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SUMMER IRRIGATION OF PIMA COTTON[1]

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INTRODUCTION

Summer irrigation problems need to be distinguished from those of the spring months. In the spring the problem is chiefly one of controlling the growth of the young plants and their habits of branching so as to avoid excessive vegetative development. After these early stages are passed, and the plants are flowering and fruiting, the question is how often to apply water to the best advantage for the development of a maximum crop. The answer will depend upon differences in soil and other conditions that affect water requirements, but treatment can be adjusted to the needs of the crop, as indicated by the behavior of the plants.

A first experiment with summer irrigation, recognized as a distinct problem, was made with Pima[2] cotton at the Cooperative Testing Station,[3] Sacaton, Ariz., in 1920,[4] and yielded some interesting and entirely unexpected results. The plan was to compare the behavior of plants, to which different frequencies of irrigation had been applied, after they had reached a normal early fruiting stage. In a series of such comparisons the results were alike, with no such differences of growth as have been observed in many experiments that included earlier stages of plant development. The general indication is to confirm and emphasize the importance of controlling the early development of cotton in order to bring the plants to a normal early fruiting stage. When this condition is established summer irrigation problems are simplified.

RECOGNITION OF A NORMAL FRUITING STAGE

Early in July, when the experimental treatment began, the plants were about 18 inches high and had from five to eight fruiting branches, were mostly without vegetative branches, and just beginning to flower. This form of plant is recognized as the early fruiting stage of a normal development. The plants had been brought to this condition by withholding water in the early growing period and by delaying thinning until the plants were from 10 to 14 inches high. This was done in order to check any tendency of the plants to grow rank, or put out an excessive number

[1] Accepted for publication July 2, 1922.

[2] Pima is a variety of Egyptian cotton bred and developed by the Department of Agriculture and is grown extensively in the Salt River Valley of Arizona and the Imperial and San Joaquin Valleys of California.

[3] The Cooperative Testing Station is located in the Gila River Valley at the Indian village of Sacaton and is approximately 30 miles southeast of Phoenix, Ariz. The soil and climatic conditions are similar in many respects to those in the Salt River Valley.

[4] An effort was made to repeat the experiment in 1921 on the same plots with as nearly as possible the same treatments, but spring conditions were very unfavorable so that regular stands were not secured and rains in July and August interfered with the control of growth by irrigation, so that comparable results were not obtained.

of vegetative branches. It so happened that no irrigation was required until July when the treatments began. Copious winter rains and cold spring weather may possibly explain why water was not needed earlier.

Previous experiments have demonstrated that the most desirable and productive type of plant is one which utilizes to the fullest extent in fruiting development the space apportioned to it, without injury to its neighbors. Such plants have no vegetative branches, or only one or two, depending on spacing. To grow plants of this type it is necessary to observe precautions in thinning and avoid any unnecessary irrigation when the plants are young and easily forced into undesirable vegetative growth. When precautions are not taken the plants may develop several vegetative branches and become so crowded that only a late crop can be produced.

It is essential that the present experiment should not be confused with others that have been published, that dealt with the early development and control of the branching habits of the plants.[5] The treatment cotton receives before fruiting begins undoubtedly is reflected in all of the subsequent behavior of the plants and is a factor in determining the water requirements during the fruiting period. The objects and conditions of experiments in the spring differ from those of the summer; hence the treatments are distinct problems.

CLIMATIC CONDITIONS

As the weather during the cotton-growing season is an important factor in judging the results of experimental data, a summary of the records is given.

The season of 1920, though unusual in many respects, was more favorable for a reliable consideration of several cultural features than could be had in a normal year. Lack of heavy summer rains made the irrigation problems more definite, and an unusually cool spring assisted materially in controlling the early growth of the plants. On the other hand, the maximum air temperatures in July were unusually high, providing a test of the effects of hot weather.

Table I gives the monthly average maximum and minimum temperatures from March to October, inclusive, for the years 1910 to 1919, the 10-year average for each month, and the monthly averages for 1920. In comparing the average monthly maximum and minimum temperatures for 1920 with the averages for the corresponding month in the preceding years it will be seen that those for 1920 generally are lower, and, with the exception of the July maxima, are all below the 10-year average.

The first killing frost occurred on November 29, but there had been light frosts, which did little damage, as early as October 14. For a period of 10 consecutive years prior to 1920 the average date of the first killing frost at Sacaton is November 17.

The summer rains, which usually occur in the latter part of July and the early part of August and are a complicating factor in the problem of irrigation of cotton, were almost negligible in the season of 1920, as shown in Table II. This precipitation has not been considered, since the showers were so slight and so widely separated that the plants were not affected, but the data are presented in Table III.

[5] COOK, O. F. A NEW SYSTEM OF COTTON CULTURE AND ITS APPLICATION. U. S. Dept. Agr. Farmers' Bul. 601, 12 p., 2 fig. 1914.
—— SINGLE-STALK COTTON CULTURE. U. S. Dept. Agr. Bur. Plant Indus. Crop Acclim. and Adapt. Inves. B. P. I. Doc. 1130, 11 p., 12 fig. 1914.

TABLE I.—*Average monthly maximum and minimum temperatures from March to October, inclusive, Sacaton, Ariz., from 1910 to 1919*

AVERAGE MAXIMUM TEMPERATURE (DEGREES FAHRENHEIT)

Year.	March.	April.	May.	June.	July.	August.	September.	October.
1910	87.3	89.9	99.2	104.9	106.1	104.5	103.5	91.3
1911	83.7	86.2	94.0	103.1	99.3	102.8	98.7	85.7
1912	72.1	77.9	91.9	104.1	101.3	100.2	97.7	84.5
1913	73.2	87.8	93.8	100.0	103.1	104.3	100.0	87.5
1914	80.0	86.9	96.0	99.7	103.0	107.0	100.0	84.9
1915	75.5	84.3	85.6	103.9	105.1	106.0	100.4	95.5
1916	84.0	87.4	95.5	105.9	105.7	103.4	99.7	86.2
1917	73.7	81.6	86.7	103.6	102.5	99.9	95.6	91.3
1918	75.1	82.4	87.5	101.9	100.0	97.1	97.9	87.1
1919	70.5	83.7	90.4	100.5	97.6	99.5	92.9	80.6
Av. of 10 years	77.5	84.8	92.0	102.8	102.4	102.5	98.6	87.5
1920	71.4	78.9	91.0	99.0	104.5	99.0	95.3	82.6

AVERAGE MINIMUM TEMPERATURE (DEGREES FAHRENHEIT)

Year.	March.	April.	May.	June.	July.	August.	September.	October.
1910	40.4	50.4	57.3	65.4	73.5	74.8	70.2	52.3
1911	46.4	48.7	52.5	64.6	72.7	76.2	65.8	52.3
1912	44.3	46.3	55.6	64.9	69.5	70.8	58.5	53.4
1913	38.7	49.0	56.0	62.7	70.6	73.1	64.2	48.5
1914	44.2	48.5	56.3	70.2	75.0	76.0	65.0	53.9
1915	39.1	49.4	52.1	63.6	70.0	72.0	62.6	49.8
1916	45.6	50.6	52.6	63.1	73.3	72.9	66.2	49.1
1917	36.7	46.6	55.6	62.6	75.9	69.2	68.0	54.4
1918	47.5	47.6	53.0	70.6	73.2	69.1	65.1	52.5
1919	38.4	48.5	57.4	63.2	74.0	72.4	66.8	49.6
Av. of 10 years	42.1	48.6	54.8	65.1	72.8	72.7	65.2	51.6
1920	41.2	44.3	53.2	60.4	70.7	70.1	61.3	48.6

TABLE II.—*Monthly precipitation, in inches, at Sacaton, Ariz., for an 8-month period from 1910 to 1919 compared with that for the year 1920*

Year.	March.	April.	May.	June.	July.	August.	September.	October.
1910	0.38	Trace.	.....	.....	0.65	1.45	.....	0.15
1911	.47	..do	.....	Trace.	4.11	.82	1.38	1.40
1912	2.61	.85	.38	.98	4.27	1.02	.....	.96
1913	.....	.40	.....	.92	.92	.73	.04	.18
1914	1.02	.10	.10	.34	3.25	1.77	.30	2.28
1915	1.01	1.16	.69	.10	2.44	1.05	.....	.....
1916	.71	.45	.....	.....	1.19	.63	3.61	.02
1917	.40	.11	1.29	.....	3.33	.05	.43	.....
1918	1.17	.19	.....	.20	1.49	1.92	.....	.29
1919	.55	.20	.04	Trace.	3.70	1.63	1.80	.15
Average	.83	.35	.25	.25	2.54	1.11	.75	.54
1920	1.42	.03	.17	.23	.48	.89	.21	1.21

TABLE III.—*Daily precipitation, in inches, Sacaton, Ariz., from March to October, inclusive, 1920*

Mar.	1	Trace.	July	13	.35
	10	0.47		21	.11
	23	.07		22	.02
	24	.53	Aug.	2	.28
	25	Trace.		10	.09
	27	.34		14	.01
Apr.	15	Trace.		19	.24
	19	.03		25	.27
May	21	.17	Sept.	3	.05
June	26	.13		14	.16
	27	.10	Oct.	20	.86
				31	.35

ARRANGEMENT, PLANTING, AND THINNING

The soil of the experimental plot is a black sandy loam, very well suited to the growing of cotton. Clear well water is used for irrigation, which is distributed from a concrete ditch provided with leak-proof gates. Nine sixth-acre borders[6] were used for the experiment, arranged in series of three borders each. The first series, containing borders C1–3, C1–4, and C1–5, had been in alfalfa the previous year. The other two series, covering borders C1–9 to C1–14, inclusive, and forming a solid block, had grown cotton in the previous season. The soil of series I is slightly richer than that of the others.

The experiment was planted on March 29 and April 1 with a 2-row planter, using a 44-inch row spacing, and a good stand was obtained. Unfavorable low temperatures through April and early May kept the ground cold and retarded the growth of the young seedlings. During this cold period injuries from the "sore-shin" disease were not uncommon in the Salt River Valley, while at Sacaton, with lower temperatures prevailing, the damage from this source was considerably greater, but the stand was materially affected only in a few cases.

Series I was thinned on June 4, when the cotton was about 12 inches high, leaving the plants as nearly as possible a foot apart in the row. The plants in this series were in a slightly more advanced stage of development than those of the other two series. Series II and III were thinned on June 14, when the plants had reached the same stage of development as had been attained in series I, and with the same row spacing.

PLAN OF IRRIGATION

The irrigation treatments that were applied to the three borders in each series were recorded as "normal," "medium-heavy," and "heavy," respectively. An explanation of these terms is necessary in the absence of any such definite or recognized practices.

"Normal" irrigation was the application of water in such a manner as to keep the plants flowering heavily and with little or no wilting of the leaves in the middle of the day. This is considered the best cultural practice in the Salt River Valley.[7]

"Heavy" irrigation was to apply water at definite intervals regardless of the condition of the plants or soil. As near as possible a 10-day period

[6] Border is a term applied to a portion of a field used as an irrigation unit.

[7] HUDSON, E. W. GROWING EGYPTIAN COTTON IN THE SALT RIVER VALLEY, ARIZONA. U. S. Dept. Agr. Farmers' Bul. 577, 8 p. 1914.

was allowed between irrigations of these borders. This period was known to be much shorter than usual, as irrigation records of these borders for previous years showed that intervals of 20 days or more had been used with good results.

"Medium-heavy" irrigation was planned to be intermediate, as nearly as possible, between the "normal" and "heavy" treatments. These periods varied, of course, with the "normal" irrigations and ranged between 14 and 23 days, while the periods of the "normal" borders varied from 14 to 44 days.

In applying the water the borders were flooded to a depth of several inches, as uniformly as possible. In the absence of any means of measuring the amount applied, there were some fluctuations in the quantity a border received, but such differences were not considered sufficient to modify the results, in view of the generally uniform behavior of the cotton.

This plan of irrigation was adhered to in the months of July and August, during the period of maximum plant growth and the setting of most of the bolls. After the first of September the effects of irrigation were considered only in relation to the maturing of the crop, there being no advantage in further growth of the plants. Bolls that set later than September 10 at Sacaton, even if they reach mature size, are likely to be frozen and then not open.

APPLICATION OF WATER

All the borders were irrigated on July 2 for the first time after planting. At this time the plants were from 14 to 20 inches high and were just beginning to flower. The next application of water was on July 13 to the three "heavy" borders, although they showed no signs of needing more moisture. A week later, July 20, the "medium-heavy" borders were irrigated, before any indications of wilting could be detected. The "heavy" borders had their third irrigation on July 23, when they were still visibly wet and there was no practical need of more water.

About July 28 limited areas of plants in the "normal" borders in series II and III began to show wilting of the leaves in the middle of the day, although the plants were growing rapidly and not showing flowers at the top. With this indication of the need of water, these two plots were irrigated on July 30.

It was apparent from the behavior of the plants that the "normal" border of series I would not require irrigation as soon as the "normal" borders in series II and III. As a result, the irrigation of both the "normal" and "medium-heavy" borders of series I was later. For the "heavy" border of series I the 10-day interval of irrigation was maintained, as in the other series, until August 24, when this border was not watered because the plants showed unmistakable signs of distress by a yellowish green color and an almost complete cessation of growth, while the soil obviously was too wet.

After August 13, no further irrigations were required to mature the crop of the "normal" and "medium-heavy" borders in series I, but the corresponding borders of series II and III received two irrigations in September. The need of water in September was indicated by a more yellowish color of the foliage, although the leaves did not wilt in the cooler weather. The "heavy" borders in all three sections were irrigated once in September, but water was needed earlier in series I than in series II and III.

The irrigation dates for the borders of each series during the season are given in Table IV.

TABLE IV.—*Irrigation dates*

SERIES I, IN ALFALFA, 1919

"Normal;" C1-3.	"Medium-heavy," C1-4.	"Heavy," C1-5.
July 2	July 2	July 2
	20	13
		23
		Aug. 3
Aug. 13	Aug. 13	13
		Sept. 3

SERIES II AND III IN COTTON, 1919

"Normal," C1-9 and C1-12.	"Medium-heavy," C1-10 and C1-13.	"Heavy," C1-11 and C1-14.
July 2	July 2	July 2
	20	13
		23
		Aug. 3
30	Aug. 6	
		13
Aug. 20	20	
		24
Sept. 7	Sept. 7	
28	28	Sept. 28

A summary of the data in Table IV shows that the "normal" borders of series I received only two irrigations in July and August, as compared with three irrigations of the "normal" borders in series II and III. The "medium-heavy" borders were given three irrigations in series I during the same months and four irrigations in series II and III. The "heavy" border in series I had five irrigations in July and August, while in series II and III they received six.

METHODS OF RECORDING PLANT BEHAVIOR

As a means of keeping a record of the behavior of the plants during the fruiting season, general notes and comparisons of the condition of the plants in all the borders were made frequently. More detailed observations were made on the rates of growth, the numbers of flowers produced, and the shedding of young bolls. Such data were recorded from July 6 to September 15, inclusive, and were obtained from sections of rows containing 25 plants, selected early in the season to represent as fairly as possible the plants of the border.

In determining the rates of growth, the heights of the plants in the selected sections were measured carefully each week. The flowering notes were obtained by counting the number of flowers opening daily.

Shedding data were obtained by placing dated tags on all the flowers, the tags being fastened to the pedicels of the flowers so as to remain attached even if the flower or young boll was shed and fell to the ground. Each day when new flowers were being tagged, all of the young bolls which had shed were picked up and their flowering and shedding dates were recorded.

GROWTH OF THE PLANTS

During the early stages the plants developed rather slowly. The prevailing cool temperatures of April and May somewhat retarded the growth, and the plants averaged only 8 inches high in the latter part of May. An increased rate of growth was recorded in June, when the weather became very warm, but water was withheld in order to check any tendency for the plants to become rank or to produce vegetative branches. At the same time careful watch was kept to see that there was sufficient moisture available for a steady growth. The increase in height of the plants was approximately 10 inches during the month of

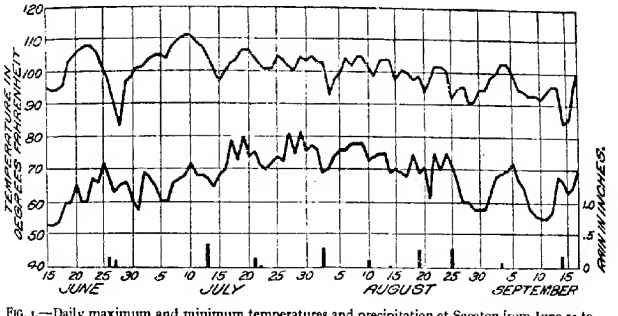

FIG. 1.—Daily maximum and minimum temperatures and precipitation at Sacaton from June 15 to September 15.

June. After the irrigation of July 2, when the experimental treatment began, the plants grew more rapidly but maintained a normal, fruitful habit.

Later development was marked by the uniformity of growth in all borders, notwithstanding the diversity of irrigation treatments. As shown in Table IV, which gives the average growth per week of 25 plants in each border and the average increase per week of the three borders that were treated alike, the development of the plants was at about the same rate throughout all the borders. It will also be seen that the plants in all the borders grew rapidly during July and early August, averaging an increase of 4.5 inches per week. During the week August 12 to 19 a decided decrease in the rate of growth was recorded in all borders, the plants growing an average of only 1 inch. A comparison of Table V with the climatological data presented in figure 1, shows there was no decided drop in temperature coincident with this retardation of plant growth, but during that week two small showers fell and there was general cloudiness of the weather. There is no reason to believe that moisture deficiency was the cause of the lower growth rate, as five of the nine borders had been irrigated on August 13, whereas the slower growth was recorded in all the borders. An increased rate of growth was obtained

during the following two weeks, although the mean temperature was slightly lower, but the weather was less cloudy with one rain on August 25. During the first week in September the growth became almost negligible, amounting to only 0.6 inch, and further records were not at-

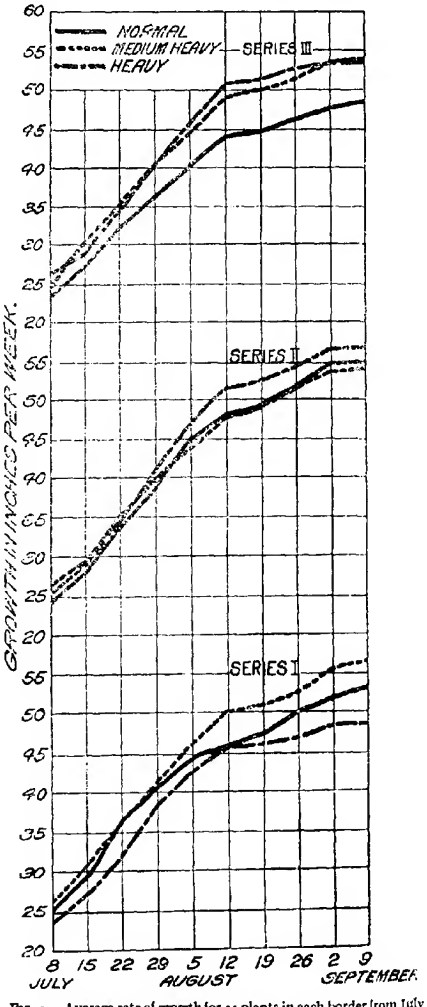

FIG. 2.—Average rate of growth for 25 plants in each border from July 8 to September 9.

tempted in view of the difficulty of detecting small differences in the height of the stalks.

A diagram showing the weekly rate of plant growth for the borders of each series is given in figure 2. It can be seen that at the end of the

growing season the average height that finally was reached by the "normal" borders (52.1 inches) was little different from that obtained in the "heavy" borders (52.9 inches) or in the "medium-heavy" borders (54.8 inches). There was no indication that the different amounts of moisture had affected the rate of growth, though it should be remembered that at no time was the amount of moisture allowed to get so low that the plants suffered noticeably, even in the "normal" borders that received the least water. The conclusion is that the additional or surplus water applied to the other borders was not utilized in making larger plants.

TABLE V.—*Average height in inches of 25 plants in each border by weeks from July 8 to September 9*

Date.	Normal irrigation.				Medium-heavy irrigation.				Heavy irrigation.			
	C1-3.	C1-9.	C1-12.	Average increase per week.	C1-4.	C1-10.	C1-13.	Average increase per week.	C1-5.	C1-11.	C1-14.	Average increase per week.
July 8	25.6	24.2	23.4	.....	26.1	26.3	24.2	.....	23.8	25.4	26.1	.....
15	29.9	28.0	27.6	4.1	30.9	29.4	30.3	4.7	27.1	28.7	29.1	3.2
22	36.5	34.0	32.6	5.8	36.4	35.1	35.4	5.4	32.0	34.3	34.8	5.4
29	40.6	38.7	36.3	4.2	41.0	39.9	40.3	5.0	38.2	41.0	40.3	6.1
Aug. 5	44.3	44.8	40.5	4.7	46.3	43.4	44.6	4.1	42.9	47.0	45.8	5.4
12	45.8	48.0	43.8	2.6	50.0	47.4	49.4	4.2	45.2	51.2	50.6	3.8
19	47.4	49.0	44.4	1.1	51.0	49.0	52.0	1.1	45.9	52.4	51.3	.8
26	50.0	51.5	46.3	2.4	52.5	51.4	51.7	2.9	46.6	54.0	52.6	1.3
Sept. 2	52.0	54.3	47.7	2.0	55.8	53.4	53.4	2.3	48.2	56.2	53.4	1.5
9	53.2	54.6	48.5	.8	56.8	54.0	53.8	.7	48.6	56.8	53.4	.3

Under some conditions the absence of any appreciable or consistent difference in the development of the plants in any of the treatments might be ascribed to lack of soil fertility. This possibility was considered, but the fact that in the previous year cotton has grown 6 to 7 feet tall on some of the land included in series II and III is thought to be sufficient evidence of an abundance of available plant food. Hence it is believed that the general uniformity of growth should be attributed to the stage of development the plants had attained before irrigation began rather than to the state of fertility of the soil or subsequent influences.

It is to be recognized, of course, that with other seasonal conditions, as hot weather in the spring or heavier rains in the summer, such uniformity of behavior might not have been maintained; but this does not make it less important to know how uniform the behavior may be under favorable conditions and how little difference was secured by such varied frequencies of irrigation as were included in this experiment.

DAILY PRODUCTION OF FLOWERS

The first flowers appeared early in July, and the record of flower production was started on July 6. At this time there were only 2 or 3 flowers opened per day on 25 plants, but the rate rapidly increased with the growth of the plants. The highest production was reached on July 31, with a maximum period extending for approximately 20 days, beginning about July 28 and ending about August 17. During this period an average of about 1¼ flowers per plant per day was sustained. On September

15, when the flowering had almost ceased, there had been produced from 40 to 50 flowers per plant.

The daily flowering records of the 25-plant sections for each border are shown in Table VI. Although the results are in general harmony with the data of plant growth, this may not be apparent at first on account of the rather wide fluctuations, which no doubt are due in part to the limited numbers of plants included in the record. The general consistency of flowering behavior of the different treatments is more plainly shown by the superposed curves (fig. 3), which represent the totals of daily flower production of the three treatments, summarizing all the records of Table VI, and by the flowering curves of the three borders of series II (fig. 4).

By referring to Table VI, it will be seen that significant differences did not result from any of the three irrigation treatments, either in the number of flowers produced daily or in the total numbers of flowers

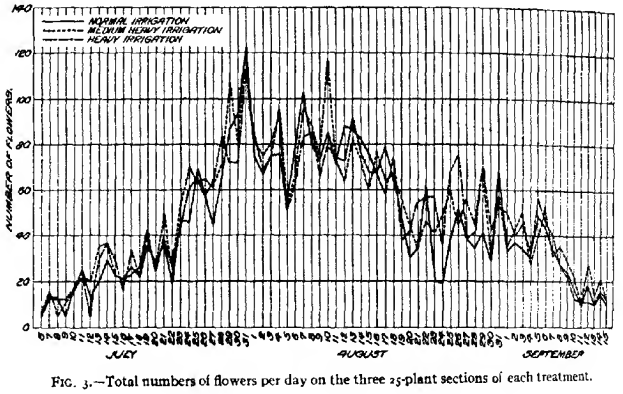

FIG. 3.—Total numbers of flowers per day on the three 25-plant sections of each treatment.

produced by each border for the season. This was due, no doubt, to the fact that the plants differed but little in size. That the total numbers of flowers produced on the 25-plant sections were not exactly proportionate to the numbers produced by each border as a whole can be seen by comparing these totals with the yield of seed cotton per border. The yields are the practical summaries, while the daily records serve as an index of the behavior of the plants.

A pronounced variation in the number of flowers opening from day to day often occurred in this experiment throughout the entire season, but independent of the irrigation treatment. Regardless of when or how often a border had been irrigated, there were days when all the borders had large numbers of flowers. Conversely, on days when only a few flowers opened the same tendency was generally apparent in all of the borders. This general coincidence in flowering becomes very striking when the flowers per day for the three borders treated alike are combined, giving the total flowers per day on 75 plants. From figure 3, it will be seen that the curves of the different treatments follow each other to a marked degree, although the range from day to day is often large.

Effort was made to correlate these fluctuations with temperatures and other factors, and some indications of correlation were found, but not enough to justify elaboration on the basis of such limited material. Until more definite knowledge is gained as to when the opening of a bud is determined, or what combinations of conditions cause the stimulus to be given, there is little basis for figuring correlations. The fluctua-

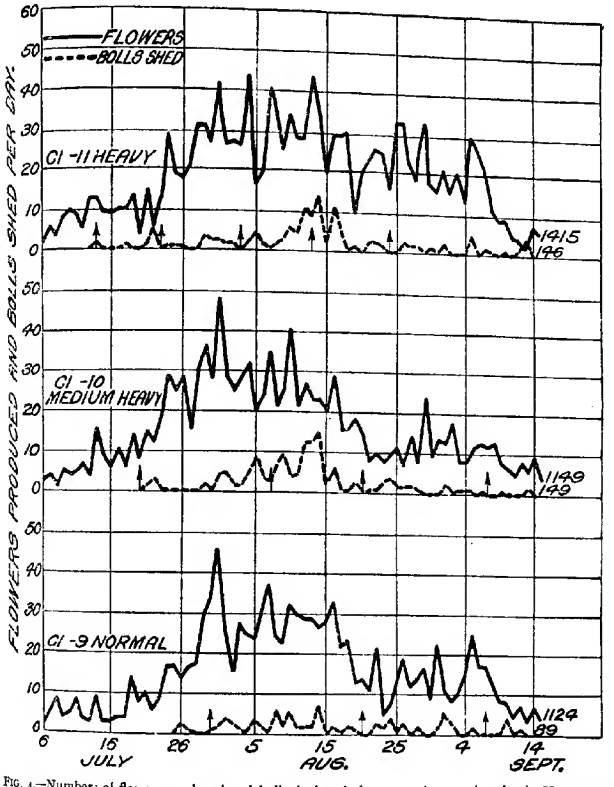

FIG. 4.—Numbers of flowers produced and bolls shed each day on 25-plant section of series II, compared with the irrigation dates. Note the lack of consistency of behavior at any regular period after irrigation. The arrows indicate irrigation dates.

tions shown in figure 3 give a general impression of periodicity, but there is no evidence of regularity. Also, the general consistency of flower production between borders would seem to indicate a short period between the determining factors, or stimuli, and the flowering dates; but with so little known regarding these features, it seems better to present the data without hazarding explanations.

TABLE VI.—*Numbers of flowers per day on the 25-plant section in each border* [a]

Date.	Normal irrigation.				Medium-heavy irrigation.				Heavy irrigation.				Grand total.
	Cr-3.	Cr-9.	Cr-12.	Total.	Cr-4.	Cr-10.	Cr-13.	Total.	Cr-5.	Cr-11.	Cr-14.	Total.	
July 6	2	2	2	6	3	3	1	7	3	2	0	5	18
7	8	5	1	14	8	4	4	16	3	6	4	13	43
8	4	8	1	13	4	1	1	6	2	4	7	13	32
9	1	4	0	5	4	5	2	11	3	8	2	13	29
10	8	5	4	17	3	4	9	16	4	10	3	17	50
11	10	8	7	25	11	5	6	22	6	9	9	24	71
12	7	4	2	13	6	7	7	20	0	5	0	5	38
13	12	3	4	19	19	4	12	35	[a] 10	[a] 13	[a] 5	28	82
14	10	9	10	29	13	16	8	37	11	13	13	37	103
15	11	3	8	22	9	9	11	29	10	9	3	22	73
16	11	3	7	21	7	6	4	17	6	9	6	21	59
17	17	4	5	26	10	10	14	34	9	10	4	23	83
18	9	4	9	22	13	6	3	22	12	10	4	26	70
19	11	14	10	35	15	14	12	41	19	14	9	42	118
20	14	8	6	28	[a] 20	[a] 8	[a] 8	26	9	4	12	25	79
21	20	10	7	37	18	15	17	50	14	15	10	39	126
22	5	6	8	19	6	12	8	26	8	6	14	28	73
23	16	9	21	46	17	19	18	54	[a] 20	[a] 14	[a] 9	43	143
24	19	17	10	46	22	29	20	71	18	28	15	61	178
25	28	17	24	69	21	25	17	63	27	19	20	66	198
26	23	14	19	56	24	28	13	65	20	18	19	57	178
27	18	17	10	45	25	16	20	61	18	21	25	64	170
28	20	18	30	68	17	31	25	73	21	31	31	83	224
29	31	29	27	87	40	36	31	107	20	31	21	72	266
30	30	[a] 34	[a] 30	94	24	28	30	82	22	27	23	72	248
31	33	46	41	120	39	48	34	121	37	42	34	113	354
Aug. 1	27	26	22	75	34	28	21	83	37	26	23	86	244
2	31	16	20	67	24	25	26	75	16	27	26	69	211
3	25	28	22	75	31	28	22	81	[a] 30	[a] 26	[a] 18	74	230
4	27	25	24	76	30	32	33	95	28	44	24	96	267
5	14	24	17	55	15	21	16	52	14	17	20	51	158
6	24	30	26	80	22	25	22	69	21	20	22	63	212
7	37	37	28	102	30	35	32	97	28	42	19	89	282
8	30	25	25	80	36	22	32	89	21	33	32	86	255
9	31	23	19	73	31	25	19	75	24	25	17	66	214
10	31	32	33	96	40	41	36	117	21	34	24	79	292
11	23	30	19	72	26	21	27	74	17	28	29	74	220
12	27	29	33	89	23	27	14	64	25	28	20	73	226
13	[a] 26	29	32	87	[a] 31	23	29	83	[a] 21	[a] 44	[a] 28	93	263
14	32	27	24	83	23	23	28	74	17	35	25	77	234
15	22	28	26	76	20	20	20	60	22	20	26	68	204
16	17	33	17	67	27	29	21	77	13	29	25	67	211
17	19	22	38	79	22	16	26	64	13	29	16	58	201
18	17	24	23	64	22	16	29	67	21	30	23	74	205
19	10	13	23	46	14	19	24	57	12	10	16	38	141
20	5	[a] 14	[a] 11	30	10	[a] 15	[a] 20	45	5	20	17	42	117
21	9	11	15	35	13	8	13	34	17	23	15	55	124
22	13	22	27	62	15	10	21	46	13	26	18	57	165
23	8	5	7	20	17	8	16	41	10	25	12	47	108
24	5	7	7	19	20	10	19	49	6	[a] 17	[a] 13	36	104
25	6	13	19	38	25	12	23	60	15	33	20	68	166
26	11	19	22	52	12	7	25	44	14	33	29	76	172
27	9	12	17	38	19	15	22	56	7	23	8	38	132
28	6	14	14	34	17	8	20	45	9	19	14	42	121
29	7	17	17	41	20	24	26	70	18	33	19	70	181
30	5	9	15	29	9	9	14	32	14	18	10	42	103
31	12	23	33	68	19	14	24	57	15	16	21	52	177
Sept. 1	8	11	14	33	8	13	14	35	14	22	14	50	118
2	9	8	20	37	8	18	16	42	10	16	14	40	119
3	6	10	18	34	16	8	26	50	[a] 13	21	11	45	129
4	2	15	13	30	9	8	10	27	8	14	11	33	90
5	5	25	19	49	10	12	17	39	8	30	19	57	145
6	10	17	16	43	15	13	25	53	10	26	10	46	142
7	8	[a] 17	[a] 9	34	9	[a] 12	[a] 10	31	11	21	8	40	105
8	7	12	8	27	10	13	12	35	10	12	4	26	88
9	4	8	12	24	8	8	13	29	10	9	3	22	75
10	4	8	5	17	7	7	8	22	4	9	0	13	52
11	1	4	4	9	5	5	1	11	5	5	1	11	31
12	4	7	7	18	8	8	11	27	6	4	4	14	56
13	4	3	3	10	5	6	4	15	4	2	4	10	35
14	6	7	2	15	4	10	7	21	7	7	2	16	52
15	3	4	3	10	2	4	6	12	4	6	2	12	34
Total	1,025	1,124	1,131	3,280	1,209	1,149	1,235	3,593	994	1,415	1,035	3,444	10,317
Average				1,093				1,197				1,148	

[a] Irrigation date.

Ewing [8] found in comparing the flowering curves of Trice cotton, from one plot on rich soil and another plot on poor soil, that—

> the same daily fluctuation in the flowering curve is noticeable in the two situations, and the most pronounced difference is in the height of the flowering curve.

This would agree with the results shown in figure 2, although instead of the soil being different the moisture supply was varied in our experiment, and as the moisture did not appreciably influence the rate of flowering the curves are not very different.

That the number of flowers per day was not noticeably affected by irrigation will be apparent from the diagram (fig. 4), which gives the daily flower production and the dates of irrigation for the three borders of series II. The behavior of the plants in this series is regarded as sufficiently representative of the other two series. There was no consistent behavior in either higher or lower rates of flowering at any regular interval after irrigation. This is in direct contrast to a common belief in the irrigated valleys of the Southwest that fewer flowers are produced for a few days after each irrigation, but no such relation is shown in the curves of figure 4.

It is recognized that the physical condition and size of the plants, fertility of the soil, and the amount of available moisture, undoubtedly are factors which limit the number of flowers produced; but from the data presented in figure 3 and figure 4, it seems that other influences not yet identified must determine whether the numbers of flowers on particular days shall be relatively high or low; and since it is possible to predict when a bud will flower one day and sometimes two days beforehand, it is evident that the determining influences are effective at least several days in advance.

SHEDDING OF YOUNG BOLLS

The shedding of young bolls began on July 14, but up to July 29 the rate was almost negligible, amounting to less than 1 shed boll per day for every 50 plants. A higher rate occurred during most of August, the highest number falling on August 12, but an average of the period when the maximum shedding occurred showed less than 1 shed boll per day for every 7 plants. During the latter part of August and the first two weeks in September the rate fell to less than 1 shed boll per day for 25 plants.

The daily shedding records for the 25-plant sections are given in Table VII, which gives the number of young bolls shed per day in each border, the total per day for all borders, the total per border for the season, and the percentage for each border.[9] The age of the bolls when the maximum shedding occurs is given in Table VIII, showing the number of days between the opening of the flowers and the shedding of the young bolls within a period of 30 days after flowering, with the number of bolls shed for each interval of days per border and the total for all borders.

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[8] EWING, E. C. A STUDY OF CERTAIN ENVIRONMENTAL FACTORS AND VARIETAL DIFFERENCES INFLUENCING THE FRUITING OF COTTON. Miss. Agr. Exp. Sta. Tech. Bul. 8, 93 p., 40 fig. 1918. Literature cited, p. 93.

[9] Diagrams of the shedding on series II, including borders C1-9, C1-10, and C1-11, from July 14 to September 15, derived from the data in Table VII, are shown in figure 3, where they are used for purposes of comparison with the flower diagrams and in relation to the dates of irrigation.

TABLE VII.—*Numbers of shed bolls per day and percentage of boll shedding for the season on the 25-plant section in each border*

Date.	Normal irrigation.				Medium-heavy irrigation.				Heavy irrigation.				Grand total.
	Cr-3.	Cr-9.	Cr-12.	Total.	Cr-4.	Cr-10.	Cr-13.	Total.	Cr-5.	Cr-11.	Cr-14.	Total.	
July 14	1			1						2		2	3
15													0
16											1	1	1
17			1	1	3		2	5					6
18					1			1	1	1		2	3
19													0
20					[a] 2	(a)	(a)	2	1			1	3
21						2	1	3		1		1	4
22	2		1	3	4	3		7	3	6		9	19
23							2	2	(a)	(a)	(a)		2
24	1		1	2						1	1	2	4
25					1			1		1	2	3	4
26	1	3		4	1			1	1	1		1	6
27	2	1		3	1			1	1			1	5
28					1			1					1
29	6		2	8	4	2	1	7		4		4	19
30	2	[a] 1	(a)	3	1		2	3	4	3	2	9	15
31	1	2	2	5	5	5	2	12	3	3	4	10	27
Aug. 1	4	4	4	12	7	5	2	14	6	2	4	12	38
2	5	3	1	9	4	2	4	10	4	2	4	10	29
3	1	2		3	2	2		4	[a] 1	(a)	[a] 3	4	11
4	1	1	2	4	1	5	1	7	2	2	1	5	16
5	6	4	3	13	12	9	7	28	22	5	13	40	81
6	4	2	8	14	5	4	1	10	5	2	3	10	34
7	1	1	1	3	7	3	2	12	4	1	5	10	25
8	4	6	5	15	4	7	6	17	6	2	4	12	44
9	1	2	2	5	2	10	4	16	1	3	8	12	33
10	8	6	6	20	2	4	6	12	6	6	4	16	48
11	4	2	3	9	2	5	3	10	2	5	2	9	28
12	7	2	11	20	19	13	8	40	13	11	8	32	92
13	[a] 6	2	3	11	[a] 2	13	1	16	8	9		17	44
14	8	7	6	21	9	16	12	37	16	14	7	37	95
15				0		2	3	5	2	3	2	7	12
16	3	2	5	10	4	7	2	13	12	11	5	28	51
17	4	1	2	7	1	1	1	3	3	5	1	9	19
18	2	2	1	5		1	2	3		1	2	3	11
19	4	1	10	15	3	3	9	15	2	2	3	7	37
20		(a)	(a)	0	2	(a)	(a)	2	1		2	3	5
21				0	3	1		4	1	3	2	6	10
22	4	3	2	9	8	1		9	3	3	2	8	26
23	3	2	1	6	2	3		5	4	2	2	8	19
24	2	4	1	7	5	4	4	13	2	(a)	[a] 1	3	23
25	6	1	4	11	1	2	1	4			1	1	16
26		3	8	11	1	2	6	9		3	4	7	27
27	3			3	3	2	2	7	2	2		4	14
28	2	2		4		1	1	2	1	2	1	4	10
29				0				0		1	1	2	2
30				0	1		1	2		2		2	4
31		2	1	3	1			1		1		1	5
Sept. 1	1	5		6		3	2	5		3	3	6	17
2		3	3	6			2	2		1	1	2	9
3	1			1		1		1	[a] 2			2	4
4	1		1	2	5	1		6	1			1	9
5	2	2	1	5	1			1		5	1	6	12
6	1			1		1		1				0	2
7		(a)	(a)	0		(a)	[a] 3	3	1	2		3	6
8				0				0	1	1		2	2
9				0		1	2	3			7	7	10
10		4	1	5	2			2	1	1	3	5	12
11			1	1			1	1				0	2
12		1	1	2			2	2		2	4	6	10
13	4		2	6	3	2	4	9	2	4	2	8	23
14	1			1				0			1	1	2
15	1			1				0			0	0	1
Total shed	121	89	107	317	148	149	115	412	150	146	127	423	1,152
Total flowers	1,025	1,124	1,131	3,280	1,209	1,149	1,235	3,593	994	1,415	1,035	3,444	10,317
Percentage shed	11.8	7.9	9.4	9.7	12.2	12.9	9.3	11.4	15.0	10.3	12.5	12.6	11.2

[a] Irrigation date.

TABLE VIII.—*Number of bolls shed for each day after flowering*

Number of days after flowering.	Normal irrigation.				Medium-heavy irrigation.				Heavy irrigation.				Grand total.
	Cr-3.	Cr-9.	Cr-12.	Total.	Cr-4.	Cr-10.	Cr-23.	Total.	Cr-5.	Cr-11.	Cr-14.	Total.	
1						1	1	2			1	1	3
2	1			1		1		1		1	1	2	4
3	1	1	1	3					1	3	3	7	10
4	5	2	2	9	5	5	4	14	8	5	6	19	42
5	8	2	7	17	7	14	4	25	7	4	4	15	57
6	4	9	10	23	11	20	6	37	11	16	11	38	98
7	12	8	11	31	13	8	15	36	14	15	18	47	114
8	15	7	10	32	21	18	13	52	12	14	12	38	122
9	10	10	18	38	11	15	6	32	14	15	11	40	110
10	9	6	10	25	15	9	10	34	15	14	10	39	98
11	7	8	6	21	9	13	6	28	8	10	13	31	80
12	7	1	6	14	10	8	7	25	12	9	6	27	66
13	3	4	4	11	13	9	8	30	15	6		21	62
14	8	5	5	18	6	6	1	13	3	5	6	14	45
15	3		2	5	3	4	7	14	3	3	7	13	32
16	4		1	5	3	3	6	12	3	4	1	8	25
17	5	2		7	2	2	2	6	3	6	4	13	26
18	3	4	3	10	2		2	4		3		3	17
19		4	1	5	3	2	3	8	3	1		4	17
20	2	2		4	1		2	3	1	1		2	9
21	3		1	4	2	1		3	1	1	1	3	10
22	1		1	2	1	1		2	2	2		4	8
23	2		1	3		2	1	3	3	1	1	5	11
24	1	1		2		2	1	3	2		2	4	9
25	1			1			1	1	2	2	1	5	7
26				1	1			1					2
27		1	1	2			3	3	1		2	3	8
28			1	1		1	1	2	2	1		3	6
29	1	2		3						1	1	2	5
30		1	1	2	1			1	1		1	2	5

No significant differences appeared in either the amount of shedding per day or the total for the season as a result of the varied irrigation treatments. A comparison of the records in Table VII, shows that the number per day for one treatment is not consistently larger or smaller. Differences are shown both between the borders that represent the same treatment and between the series. The total number shed for the season and the percentage of shedding are less in the "normal" treated borders, but this may not be significant in view of the small number of plants included in the daily shedding record.

As can be seen by referring to Table VII, considerable variation occurred in the number of bolls shed from day to day throughout all the borders, but the amount of shedding on certain days was often noticeably consistent in all the borders. August 5, 12, and 14 are good examples of days when heavy rates of shedding occurred, while on August 3, 15, and 20 only a few bolls were shed. These variations may be analogous to the regular fluctuations found in the opening of the flowers, which has been discussed previously, but the limited amount of material is not sufficient to use as a reliable basis of comparison.

As with the data of flowering, efforts were made to correlate the fluctuations of shedding with temperatures and other factors, but such indications were not consistent enough to justify discussion. It seems probable that several factors must be taken into account in attempting to localize and determine the causes of shedding. That shedding may occur from 4 to 15 days after flowering or may not take place until several days after the abortion is induced is only one of the many difficulties to be met.

Shedding as a direct effect of irrigation was not indicated, even on the "heavy" borders, although it is generally believed that excess moisture may cause young bolls to drop. There was no generally higher or lower rate of shedding at any regular interval after a border was irrigated. This can be seen in figure 3, or by a comparison of the irrigation dates with the daily shedding record in Table VII. That the plants retained their normal fruitful behavior throughout the experiment instead of becoming overgrown is regarded as responsible for the lack of any excessive shedding. The highest shedding rate, 15 per cent, occurred on the "heavy" border C1–5, in which the plant growth was checked, apparently by too much water. But this rate of shedding was nearly equaled on the "medium-heavy" border C1–10, which showed no abnormal behavior.

The length of the period between the date of flowering and the date of shedding of young bolls was found to fluctuate, with no indication of being affected by irrigation as applied. It is shown in Table VIII that 82 per cent of the shedding occurred between 4 and 14 days after the flowers opened, with a maximum 8 days after flowering and 10.8 days as the average age of shed bolls. That so little shedding occurred until several days after flowering is of interest and would agree with results published by Lloyd [10] for Upland varieties, who found that "abscission is inhibited during anthesis," but there are differences between the Upland and Egyptian types with respect to the time of maximum shedding. Lloyd found under field conditions in Alabama that the period of greatest shedding of young bolls was from 4 to 8 days after flowering and that "the age at which bolls were shed in maximum numbers was 5 to 6 days," while his figures show that the average period of persistence was about 6 days. Thus there are definite indications that Upland bolls shed earlier in Alabama than Pima bolls in Arizona.

In 1918 Mr. C. J. King, of the Bureau of Plant Industry, found the mean period of persistence of shed bolls in Pima cotton at Phoenix, Ariz., to be 10.3 days after flowering,[11] which is in close agreement with the period of 10.8 days obtained in our experiment at Sacaton.

Under Sacaton conditions, the Egyptian cotton differs notably from the Upland varieties, which often shed a large proportion of their buds before flowering. This was especially noticeable in 1920, when two Upland varieties, Durango and Lone Star, were compared with Pima cotton. Until the latter part of the flowering season the great majority of the squares produced on the Upland plants were dropped, while the adjoining border of Pima cotton lost very few squares. As in the irrigation experiment, the shedding which took place in the Pima border was almost entirely of young bolls. Lloyd found in Alabama that about 50 per cent of the shedding in the Upland varieties consisted of squares.

Factors which caused shedding in the experiment were probably of a general nature, as the percentage of shedding was practically the same throughout the Pima cotton on the station that was receiving a normal treatment. Less shedding occurred than usual, which may be ascribed to the lack of heavy summer rains, the few rains being too slight to affect the amount of shedding. Lack of fertilization of the flowers caused

[10] LLOYD, Francis E. THE ABSCISSION OF FLOWER-BUDS AND FRUITS IN GOSSYPIUM, AND ITS RELATION TO ENVIRONMENTAL CHANGES. *In* Trans. Roy. Soc. Canada, ser. 3, v. 10, sect. 4, p. 55–61. 1916.
—— ENVIRONMENTAL CHANGES AND THEIR EFFECT UPON BOLL-SHEDDING IN COTTON. *In* Ann. N. Y. Acad. Sci., v. 29, p. 1–131, 26 fig. 1920. Literature, p. 129–131.

[11] KING, C. J. WATER-STRESS BEHAVIOR OF PIMA COTTON IN ARIZONA. U. S. Dept. Agr. Bul. 1018. p. 15. 1922.

little, if any, loss, as bees and wasps were numerous in the fields at all times and pollination was usually accomplished soon after a flower opened. Injurious insects were noticeably absent and none of the shed bolls were found to be damaged.

INDICATION OF OVERWATERING

It became apparent about August 18 that the plants in the "heavy" border in series I were in distress. Growth had practically stopped, and the rate of flowering showed a distinct decline. Many of the lower leaves were dying and dropping off, and the other leaves had an unnatural yellowish green color. This usually would be taken as a sign of urgent need of water, but since the soil was obviously wet, even on the surface, that explanation would not serve. This border was not irrigated with the other "heavy" borders on August 23. No indication of a similar condition could be found in the "heavy" borders in series II and III, although up to this time they had received the same irrigation treatment.

In view of the fact that no similar behavior was found on the adjacent borders or elsewhere on the station, it seems probable that excess moisture was causing the distress in border C1–5, because of some peculiarity of the soil in series I, which resulted in a lower water requirement. A comparison between the number of irrigations on the "normal" border in series I and the "normal" borders in series II and III shows that series I required only half as many irrigations. Thus the same effects as the irrigation of the "heavy" border in series I every 10 days might have been obtained in the "heavy" borders of series II and III by irrigation at 5-day intervals.

The affected border was irrigated on September 3, as the plants showed wilting in the forenoon although the ground still appeared moist. A crippled, or partially destroyed root system may possibly have been responsible for this wilting, which ceased after more water was given. On September 8 it was noted that the plants had improved in color and later that the color had continued to improve so that only a slight difference could be detected.

However, the setback this border had received was very noticeable and its recovery was too late to make good the handicap it had received, as can be seen from the plant growth data (fig. 2) and the picking record (Table IX).

YIELD

The record of seed cotton picked from each border is shown in Table IX, which also gives the number of plants per row and the number with vegetative branches. Four pickings were made, and the cotton from each row was weighed and recorded separately so as to allow an accurate evaluation of differences.

From Table IX it can be seen that the total seed cotton from the "normal" border in series I was 340.6 pounds, from the "medium-heavy" border 392.7 pounds, and from the "heavy" border 280.4 pounds. In series II the "normal" border yielded 267.5 pounds, the "medium-heavy" border 274.9 pounds, and the "heavy" border 265.9 pounds. From series III, the "normal" border totaled 254.3 pounds, the "medium-heavy" border 294.6 pounds, and the "heavy" border 302.2 pounds.

As shown in the foregoing data, the yields of seed cotton from the differently treated border varied to a considerable extent, but with no consistence in regard to treatment. The greater fertility of the soil is

responsible for the larger yields in series I. For reasons already explained the comparatively poor showing of the "heavy" border C1–5 was ascribed to overirrigation and resultant checking of the plants. The yields per border of series II are not significantly different. In series III the yields of the "heavy" and "medium-heavy" borders are almost the same, but considerably more than that of the "normal" border. Hence it is believed that the heterogeneity of the soil of the borders used for the experiment was responsible for the fluctuations rather than the varying irrigation treatments.

From the evidence obtained by a comparison of the yields of all the borders, and making allowances for the "heavy" border C1–5, it may be stated that the "normal" irrigation produced, on the average, about 30 pounds less seed cotton per border than either the "medium-heavy" or "heavy" irrigation, but that between the latter two no differences developed. This lower average yield of the "normal" borders indicates that this treatment may be underirrigation. In previous seasons one of the "normal" borders, C1–12, had yielded better than C1–13 and C1–14.

TABLE IX.—*Pounds of seed cotton per border and pounds per row for each picking*

Border.	Row	First picking, Sept. 17.	Second picking, Oct. 14.	Third picking, Nov. 15.	Fourth picking, Dec. 8.	Total.	Plants per row.	Plants with vegetative branches.
C1–3, "Normal"	1	7.3	16.8	14.4	6.1	44.6	240	96
	2	10.1	23.3	16.5	6.1	56.0	256	112
	3	9.5	18.2	15.1	6.3	49.1	241	109
	4	8.3	16.0	15.5	7.1	46.9	207	79
	5	7.3	17.3	14.8	8.4	47.8	283	111
	6	8.0	14.6	18.7	8.3	49.6	181	70
	7	6.9	17.2	15.2	7.3	46.6	245	98
Total		57.4	123.4	110.2	49.6	340.6	1,653	675
C1–4, "Medium-heavy"	1	5.0	14.4	18.2	7.3	44.9	287	100
	2	8.6	20.5	21.0	10.1	60.2	218	82
	3	9.1	18.8	21.0	11.8	60.7	258	91
	4	8.1	25.6	20.0	11.1	64.8	224	114
	5	7.4	18.0	19.0	10.9	55.3	296	97
	6	6.0	14.8	21.0	12.8	54.6	239	118
	7	6.4	16.2	20.0	9.6	52.2	253	88
Total		50.6	128.3	140.2	73.6	392.7	1,775	609
C1–5, "Heavy"	1	4.4	10.7	16.0	6.2	37.3	210	57
	2	5.0	14.7	18.0	8.0	45.7	292	90
	3	5.0	12.3	16.0	6.5	39.7	231	92
	4	5.1	12.1	15.0	5.9	38.1	250	59
	5	4.6	12.8	14.0	5.6	37.0	239	85
	6	9.1	16.9	17.0	6.7	49.7	239	78
	7	4.2	10.9	12.0	5.8	32.9	285	79
Total		37.4	90.3	108.0	44.7	280.4	1,746	540
C1–9, "Normal"	1	1.9	15.1	12.0	6.6	35.6	255	92
	2	3.2	17.1	15.0	6.8	42.1	256	74
	3	4.9	14.9	14.0	6.4	40.2	232	86
	4	3.5	15.9	14.0	8.1	41.5	317	72
	5	3.1	16.5	12.0	7.0	38.6	235	78
	6	4.0	15.0	9.0	4.7	32.7	264	58
	7	4.5	16.0	12.0	4.3	36.8	260	97
Total		25.1	110.5	88.0	43.9	267.5	1,819	527

TABLE IX.—*Pounds of seed cotton per border and pounds per row for each picking*—Con.

Border.	Row	First picking, Sept. 17.	Second picking, Oct. 14.	Third picking, Nov. 15.	Fourth picking, Dec. 8.	Total.	Plants per row.	Plants with vegetative branches.
C1-10, "Medium-heavy"	1	2.8	14.1	11.0	5.9	33.8	256	89
	2	2.9	14.6	12.0	7.2	36.7	271	90
	3	4.5	16.3	15.1	6.4	42.3	249	56
	4	4.4	15.2	10.0	7.0	36.6	227	73
	5	3.1	14.0	14.0	7.2	38.3	233	57
	6	4.2	17.9	16.0	9.2	47.3	254	49
	7	3.2	15.2	13.5	8.0	39.9	283	56
Total	....	25.1	107.3	91.6	50.9	274.9	1,773	470
C1-11, "Heavy"	1	3.3	13.1	15.5	5.3	37.2	232	68
	2	3.0	13.5	14.1	5.5	36.1	206	71
	3	3.2	13.8	17.2	4.9	39.1	231	74
	4	3.0	13.6	16.1	8.4	41.1	239	64
	5	2.9	13.6	16.8	6.1	39.4	264	56
	6	3.6	14.4	13.7	6.1	37.8	232	71
	7	2.4	11.6	14.7	6.5	35.2	258	59
Total	....	21.4	93.6	108.1	42.8	265.9	1,662	463
C1-12, "Normal"	1	4.3	15.0	12.0	4.9	36.2	272	48
	2	4.1	17.4	11.8	5.4	38.7	248	53
	3	3.0	14.4	11.5	4.7	33.6	245	52
	4	3.8	16.4	9.7	5.1	35.0	261	52
	5	3.5	14.3	10.0	4.1	31.9	225	39
	6	4.0	19.1	12.5	5.0	40.6	262	54
	7	4.4	15.9	10.9	7.1	38.3	241	61
Total	....	27.1	112.5	78.4	36.3	254.3	1,754	359
C1-13, "Medium-heavy"	1	3.4	16.8	14.5	7.2	41.9	295	44
	2	3.8	15.5	12.9	6.0	38.2	252	56
	3	4.6	17.9	15.5	6.0	44.0	250	63
	4	4.5	15.2	15.3	4.7	39.7	273	54
	5	6.0	18.1	14.2	5.9	44.2	265	61
	6	6.2	17.4	14.7	6.0	44.3	271	46
	7	4.2	15.4	16.8	5.9	42.3	270	55
Total	....	32.7	116.3	103.9	41.7	294.6	1,876	379
C1-14, "Heavy"	1	6.1	14.6	16.9	7.8	45.4	269	39
	2	4.3	16.0	15.5	8.3	44.1	247	31
	3	4.6	16.1	17.1	9.0	46.8	269	50
	4	4.6	13.9	16.8	6.5	41.8	228	74
	5	5.1	13.5	18.1	8.4	45.1	274	52
	6	5.1	13.9	17.7	8.9	45.6	262	54
	7	4.8	11.7	10.9	6.0	33.4	250	48
Total	....	34.6	99.7	113.0	54.9	302.2	1,799	348

A general agreement was found throughout pickings of the different treatments, the largest picking of the "normal" borders was always the second, that of the "heavy" borders the third, while from the "medium-heavy" borders the second and third pickings were about equal. It seems that the effect of more frequent applications of water tended to the later maturity of the crop.

CONCLUSIONS

Recognizing summer irrigation as a distinct problem, experiments were conducted at Sacaton, Ariz., to determine the effects of different frequencies of irrigation during the months of July and August on Pima Egyptian cotton that had reached a normal early fruiting stage.

Nine irrigated plots or "borders" were arranged in three series, affording three independent tests of contrasted irrigation treatments. Each series included a "normal" border irrigated according to the usual practice of applying water as indicated by the behavior of the plants, a "heavy" border receiving irrigations at frequent intervals, and a "medium-heavy" border receiving an intermediate irrigation treatment.

The behavior of the plants in each of the borders was observed and compared, and the data of the principal features, including growth, flowering, shedding of young bolls, and yields, were recorded through the season.

As a general result of the experiment it was determined that the different frequencies of irrigation, after the plants had reached a normal fruiting stage, did not cause any consistent significant difference in the growth of the plants, or in the yields.

No consistently different rates of flowering or of shedding of young bolls resulted from any of the different kinds of treatment.

A wide range in the daily flowering production occurred, there being days when all borders had large numbers of flowers and days when all borders had a few flowers. The rate of shedding of young bolls also varied from day to day, though on only a few days was there a consistent behavior throughout all the borders. No correlation between these fluctuations and factors which might be supposed to influence this phenomenon could be definitely established.

No consistent increase or decrease at a regular interval after an irrigation was found, either in the flowering or in the shedding of young bolls.

Shedding of young bolls was greatest from 4 to 14 days after flowering, the interval varying only slightly between borders. The shedding of flower buds, or "squares," was almost negligible throughout the experiment.

Plant development was checked and other symptoms of distress appeared in one of the three heavily irrigated borders, apparently from an excess of water.

The yields varied in the differently treated borders, but from heterogeneity of the soil rather than from the different frequencies of irrigation or in the loss of bolls by shedding.

The experiment indicates the importance of giving more attention to the spring treatment of cotton, so as to have the plants in a normal fruiting condition when summer irrigations begin. When this normal fruiting condition is attained, the summer irrigation problems are simplified, since the plants are not so easily forced into rank growth by the application of water in excess of the actual requirements.

PERMANENCE OF VARIETY IN THE POTATO[1]

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The practice of selection within the clone in order to maintain and improve the productivity and quality of potato varieties is of comparatively recent origin. In the early period of potato improvement, hybridization with subsequent selection of the most promising seedlings was the method employed. The practice of vegetative selection is founded for the most part on the success of numerous attempts to isolate high-yielding and low-yielding strains. Many investigators consider that the greatest benefit to be derived from selection is the maintenance of the optimum vigor of the variety, while other investigators believe that the results indicate the presence of inherited differences within the variety and have therefore considered selection to be of value in the improvement of varieties. Recent advances in the knowledge of certain diseases hitherto unrecognized have thrown considerable doubt upon the correctness of the latter interpretation. This study has for its primary object a determination of the effect upon the variety of selection as practiced by growers and a determination of the stability of regional differences, when the disease factor is eliminated.

REVIEW OF LITERATURE

The older theory suggested by Knight (*10*)[3] and Aitken (*1*) of varietal senility has given place to that of the deterioration of seed stock. Since selection has for one of its primary objects the prevention of this deterioration, a brief historical review of these theories will be of interest.

As early as 1787 William Marshall (*12*), writing from England, reported that potato varieties were transitory in each district. He noted that the declining varieties were characterized by curled tops. Cathcart (*3*) quotes Stephens' (*19*) "Book of the Farm" as authority for the statement that the condition of curl was first observed in 1764. Marshall (*12*) considered curl to be due to varietal senility, as it was noted that new varieties secured from seed were not subject to this condition. The following statement by Knight (*9*), in 1807, indicates the transitory nature of potato varieties at that time.

> Dr. Hunter [*8*] in his Georgical Essay, I think, has limited the duration of a variety in a state of perfection to about fourteen years; and probably taking varieties in the aggregate, and as the plant is generally cultivated, he is nearly accurate.

[1] Accepted for publication Feb. 15, 1922. Paper 298 of the Journal Series of the Minnesota Agricultural Experiment Station, published with the approval of the Director.

[2] The experiment was originated by A. W. Aamodt, who collected the original lots of potatoes, took descriptive data, and supervised the planting in the spring of 1917. The work was carried on under the supervision of Richard Wellington from the time of its inception until the spring of 1919. Thanks are due to O. I. Bergh, of the North Central Substation, Grand Rapids, Minn., Mark Thompson, of the Northeast Substation, Duluth, Minn., and Thomas McCall, of the Northwest Substation, Crookston, Minn., for their cooperation.

[3] Reference is made by number (italic) to "Literature cited," p. 959-961.

In a previous publication (*10*), Knight had put forward the theory of varietal senility, although he did not lay special emphasis on the potato. His hypothesis was that all plants propagated vegetatively have their period of maximum vigor when at middle age and then become—

subject within no very distant period to the debilities and diseases of old age.

Aitken (*1*) applied the hypothesis to potatoes in 1837, and it was accepted by many later writers. Ehrenburg (*6*), in 1904, after reviewing the work of previous investigators, concluded that the idea of varietal senility was untenable. East (*4*), in 1908, came to a similar conclusion and notes—

that the people who have considered this single question are unanimous in opposition to the hypothesis of varietal senility.

Ehrenberg (*6*) considered that the hypothesis of the deterioration of seed stocks being due to unfavorable environment has some basis for its support. East (*4*) regarded disease as the most important factor to be considered in connection with the degeneracy or running-out of seed stocks. Orton (*15*), in 1914, called attention to the so-called degenerative diseases of "mosaic," "curly-dwarf," and "leafroll" and to the probable part these diseases play in the running-out of seed stocks. The general distribution of these diseases and their harmful effect on the vigor of the plant, which has been brought out by later investigators—Stewart (*20*), Appel (*2*), Melhus (*13*), Murphy (*14, p. 33–82*), Güssow (*7*), Wortley (*30*), Shultz, Folsom, Hildebrandt and Hawkins (*17*), Quanjer (*16*), Shultz and Folsom (*17*), Krantz and Bisby (*11*)—has made it increasingly clear that the so-called running-out of seed is probably nothing more than a manifestation of these diseases.

Very little attention was paid to the possibility of improving varieties by means of asexual selection previous to the latter half of the nineteenth century. It has apparently never been considered worthy of serious attention by investigators in the British Isles. Sutton (*22*), in 1899, and Wilson (*29*), in 1907, in their discussion on the improvement of potatoes have expressed their belief that the seedling was a finished product and that further selection was of no value in its improvement. On the Continent and in the United States and Canada numerous investigators have attempted to ascertain its value. The meagerness of details in most of the earlier published reports on selection experiments makes them of little value in determining the place that selection occupies in the improvement of the potato. The most important papers on the value of selection have been reviewed by East (*4*), in 1908, and more recently by Stuart (*21*), in 1915. East (*4*), after reviewing the work of previous investigators, pointed out that the evidence was inconclusive and called attention to the influences which tended to obscure the results obtained by these investigators. Waid (*24*), in 1907, at the annual meeting of the American Breeders Association reported the results of studies on hill selection of seed potatoes. The results showed quite clearly that the progeny of low-yielding hills remained unproductive in comparison to the progeny of high-yielding hills. The favorable results reported in this work caused considerable emphasis to be placed on this method of improvement. The following year Webber (*25*) put forward a method of selection, known as the tuber-unit method, which has received considerable attention. East (*5*), in 1910, suggested that Waid's results might have been influenced by the size of the seed piece used and the fact that Waid might not have been dealing with a pure strain, as he

apparently used a commercial stock. East found no difference in yield between the progeny of high and low-yielding hills in stock which was obtained from a single tuber of the Rural New Yorker variety. He believes that great caution should be exercised in recommending asexual selection to commercial growers as a means of actual improvement of the crop, in view of the facts that of many investigations on the point no indisputable evidence of improvement has been reported and that even the questionable instances of positive results are extremely rare.

Stuart (*21*) reported in 1915 the results obtained in some rather extensive studies on the value of the tuber-unit and hill-selection methods as a means of potato improvement. Remarkable dissimilarities were found between individuals under both the tuber-unit and the hill-selection methods. Stuart did not attempt to explain the cause of the differences further than to point out that in certain instances—

> other causes than that of inherent unproductiveness must have operated to lower the yield,

and states—

> that the tuber unit method and hill selection method of improvement are chiefly valuable in pointing out the weak, unproductive, and diseased tuber.

Stewart (*20*) in his observations on some degenerate strains of potatoes states that—

> it is doubtful if any method of seed selection will prevent the "running-out" of seed potatoes under certain conditions.

In a recent article Whipple (*27*) has published the results of five years' work in pure-line selection. He calls attention to the persistency with which degenerate types (curly-dwarf) appear in pure lines and the consequent difficulty of interpreting yield data. Similar experiences have been recorded by Wellington (*26*) in a paper in which he points out the uselessness of hill selection under conditions where rapid deterioration or running-out is prevalent. The deterioration mentioned by Wellington was expressed by the production of the so-called "curly-dwarf" type of plants. This was later found by Krantz and Bisby (*11*) to be due to a disease very similar in its nature to mosaic and is probably nothing more than a severe expression of this disease.

A few experiments have been conducted to test the effect of asexual selection on characters other than yield. The results of a carefully conducted experiment for the purpose of determining the effect of selection for high and low nitrogen content was reported by East (*5*) in 1910. No difference in nitrogen content was found during three years of continuous selection. In conclusion East says—

> that neither the relative content of dry matter nor that of nitrogenous matters of the potato can be changed by the selection of fluctuations.

In attempting to isolate a blight-resistant strain of potatoes Stuart (*21*) obtained indifferent results. After selecting for three years to improve the form of the White McCormick variety, White (*28*) concluded that no improvement could be secured in this variety through selection. As previously mentioned, Stewart (*20*) and Wellington (*26*) were unsuccessful in trying to isolate a strain of potatoes resistant to factors causing degeneracy.

The evidence presented does not offer much encouragement to the plant breeder for the use of asexual selection for improving the potato. The opportunity that the mechanism of sexual reproduction offers for

the segregation and recombining of characters makes the method of hybridization with the subsequent selection of seedlings a more promising method for potato improvement. It has frequently been assumed that sufficient variation existed in all varieties to justify the grower in attempting improvement by asexual selection.

METHODS AND MATERIALS

In the fall of 1917 six lots of Early Ohio potatoes were secured from growers in different parts of Minnesota. Five of the lots were from growers who had practiced little or no selection. The sixth was from a grower who has practiced continuous mass selection of tubers for vigor and type in the same seed stock for approximately 20 years. In 1919 a seventh lot of Early Ohios was obtained from a grower who had practiced continuous mass selection of tubers for vigor and type in the same seed stock for 21 years. The growers differed in their ideas of what constituted the ideal type of the Early Ohio variety and had selected toward divergent types. Attention is called here to the fact that these two seed stocks were known to be separated for more than 20 years. This would seem to allow ample time for strains to develop within the seed stocks if there was a tendency for this condition to occur. The various lots represented distinct regional types found within the state. While it was recognized as a possibility that these seed stocks might not be asexual progeny of the same variety, it was still considered that a study of them would be of interest in determining the value of selection as practiced by the growers.

EFFECT OF SELECTION AND ENVIRONMENT ON THE POTATO PLANT

EFFECT ON PRODUCTIVITY

Results are presented in Table I showing the original source of the seed stock, the years in which the lots were tested, and their yield for each year at the places tested. The exact number of years the seed stock was grown at the place from which it was obtained is not definitely known, further than that lots 2 and 9 were grown at the places indicated for 20 or more years.

The 1917 test was carried on at University Farm, Duluth, Grand Rapids, and Crookston. The yields as presented in Table I, column III, are computed on the acre basis. The actual plot grown for each lot and locality consisted of a 4-rod row plot. The experimental error in such a test is large and the yield differences of the six lots grown are probably not significant as no lot was a consistent high or a consistent low yielder. In column IV are shown the results of the yields for 1918. These yields represented plots of three 4-rod rows computed to the acre basis. The three 4-rod rows represent seed stocks of each lot from three places—Duluth, Grand Rapids, and Crookston. The results are similar to those obtained in 1917 in that no lot gave a consistently high or low yield. In column V are shown the results obtained in 1919. The size of the plots at University Farm and Grand Rapids were the same as in 1918. At Duluth the yield given is the average yield computed to bushels per acre of two plots, each plot consisting of two 4-rod rows. As in 1917 and 1918, no lot gave a consistently high yield. Lot 7, however, gave a consistently low yield. The cause of this low yield is not clear. It could

hardly have been due to inherent difference in vigor from the other lots, since in 1917 and 1918 the yield of this lot was fully equal to that obtained from the other lots. In 1920 another lot designated as No. 9 was obtained and was grown in comparison with lots 2 and 7 at Grand Rapids. It gave an intermediate yield between these two lots.

The results of the 4-year test show no significant difference between the lots. They indicate that a significant difference probably did not exist. It is evident that the selected seed stocks 2 and 9 were not superior in vigor to the unselected seed stocks.

TABLE I.—*Productivity of Early Ohio Lots at University Farm, Duluth, Grand Rapids, and Crookston in 1917, 1918, 1920*

I, lot No.	II, source of seed, 1916.	III, yield, 1917.				IV, yield, 1918.				V, yield, 1919.			VI, yield, 1920.
		University Farm.	Duluth.	Grand Rapids.	Crookston.	University Farm.	Duluth.	Grand Rapids.	Crookston.	University Farm.	Duluth.	Grand Rapids.	Grand Rapids.
2	Anoka	205	203	326	44	253	158	286	.....	206	245	323	150
3	Grand Rapids	183	174	318	63	243	.....	.....	240	.....	.....	.....	.....
4	Faribault	216	174	311	80	272	185	.....	.....	.....	.....	.....	.....
6	Duluth	269	219	314	75	299	164	266	268	208	.....	300	.....
7	Glyndon	261	202	316	71	248	156	297	241	197	197	208	130
8	Hawley	259	179	265	56	258	.....	298	228	217	.....	249	.....
9	Hopkins[1]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	147

[1] Obtained in 1919.

The effect of seasonal conditions on the yield of the progeny is of interest. In Table II is shown the yield of the same seed stocks in 1917, at Duluth, Grand Rapids, and Crookston, and their subsequent yield in 1918 at University Farm, Duluth, Grand Rapids, and Crookston. The yield is that of a 4-rod row plot computed to bushels per acre. Column III shows that all lots gave a very low yield at Crookston in 1917 in comparison to the yield obtained at Grand Rapids, and that a yield intermediate between that obtained at these two places was obtained at Duluth. Columns IV, V, VI, and VIII show the results obtained in 1918 in tests at University Farm, Duluth, Grand Rapids, and Crookston of the different portions of the lots grown at Duluth, Grand Rapids, and Crookston in 1917. The results given show that the excessive rainfall and an early frost which caused the low yield at Crookston in 1917 and made the tubers appear worthless for seed stock had no effect on their yielding ability in 1918.

EFFECT ON FORM OF TUBER

Of the various tuber characters that are usually collectively designated as type, that of form is one of the most important. Representative tubers of some of the original seed stocks are shown in Plate 1. Lot 2, obtained from Anoka, Minn., was oval in shape, being short and broad (Pl. 1, A). Continuous selection had been practiced by the grower toward this form of tuber, which is representative of the type obtained on the sandy loam soil of the region in which it was grown. Lot 3 was obtained from the North Central Experiment Station, Grand Rapids. The

tubers of this lot were relatively long and narrow. The Early Ohio potatoes produced at this station since that time, that is in 1917, 1918, 1919, and 1920, have been relatively short and wide. Lot 4 was obtained from Faribault, Minn. The tubers of this lot were elongated and were apparently somewhat variable in form (Pl. 1, B). A few tended toward an oval form. Lot 6 was obtained from the region about Duluth. The tubers of this lot were relatively short, very broad, and considerably flattened (Pl. 1, D). Lots 7 and 8 were obtained from growers in the Red River Valley. The tubers of these lots were characteristic of the more elongated cylindrical form of the Early Ohio of this region (Pl. 1, C).

TABLE II.—*Showing that poor growth conditions at Crookston in 1917 as compared to Duluth and Grand Rapids did not affect the yield of Crookston stock in 1918*

I, lot No.	II, source of seed, 1916.	III, yield, 1917.			IV, yield at University Farm, 1918 of seed grown in 1917 at—			V, yield at Duluth in 1918 of seed grown in 1917 at—			VI, yield at Grand Rapids in 1918 of seed grown in 1917 at—			VII, yield at Crookston in 1918 of seed grown in 1917 at—		
		Duluth.	Grand Rapids.	Crookston.	Duluth.	Grand Rapids.	Crookston.	Duluth.	Grand Rapids.	Crookston.	Duluth.	Grand Rapids.	Crookston.	Duluth.	Grand Rapids.	Crookston.
2	Anoka	203	326	44	293	271	202	193	138	143	290	299	269	.....	.....	.....
3	Grand Rapids	174	318	63	242	224	263	.....	.....	.....	.....	.....	.....	249	220	249
4	Faribault	174	311	80	288	224	315	220	110	146	.....	.....	.....	.....	.....	.....
6	Duluth	219	314	75	297	293	308	165	158	169	246	247	311	301	239	255
7	Glyndon	202	316	71	336	227	271	152	178	139	256	266	359	273	155	299
8	Hawley	179	265	56	264	218	288	.....	.....	.....	314	255	256	258	191	235

A part of each of these lots were grown at University Farm, Duluth, Grand Rapids, and Crookston in 1917. The form of the tubers produced at each of these places was similar in all the lots. It was evident that regardless of the form of the tubers in the original lots the growth conditions at each place produced a uniform distinctive form of tuber. The 1917 crop was carefully studied for possible differences in form between the lots grown at any one place. It was thought that slight differences in form were observable between some of the lots grown at Duluth. These differences in form were not found to remain consistently in 1918, although a similar amount of variation between the lots was observable.

In 1919 a study was made of the ratio of width of tubers to length in order to determine its value as an index to tuber form. Correlation studies for the ratio of width to length of tubers are presented in Tables IV to VII. The coefficients are here summarized.

TABLE III.—*Relation between width and length of tubers in the Early Ohio variety in 1919*

Place grown.	Coefficient of correlation.	Number of individuals.
Grand Rapids	0.718±0.014	571
Duluth	.847± .025	326
University Farm, clay loam	.647± .032	148
University Farm, sandy loam	.601± .034	161

The data presented in these tables show that there is a decided correlation between the width and the length of tuber and that this correlation

is similar for both small and large tubers of the same lots. The ratio of width to length of tuber would therefore appear to be a very good index of form in the Early Ohio variety. This is more clearly shown in Table VIII, which shows the influence of growth conditions on the form of tubers.

TABLE IV.—*Correlation between width and length of tuber in the Early Ohio variety, grown at the North Central Experiment Station, Grand Rapids, in 1919*

[Coefficient of correlation = 0.718 ± 0.014]

Width of tubers in millimeters.	Length of tubers in millimeters.																							Total.
	46	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	110	114	118	122	126	130	
40	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
42	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2
44	...	...	2	...	...	1	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	1
46	...	1	1	10	2	1	1	2	...	1	...	...	...	...	...	...	...	...	...	...	...	...	5
48	...	...	1	9	7	5	2	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	19
50	...	1	4	7	20	9	8	3	...	1	1	...	...	...	...	...	...	...	...	...	...	...	26
52	...	...	3	7	25	12	14	2	5	2	1	...	...	...	...	...	...	...	...	...	...	...	44
54	...	...	1	2	9	17	14	7	6	9	2	1	...	...	...	...	...	...	...	...	...	...	61
56	...	1	...	3	4	7	12	9	9	...	3	2	1	1	1	...	...	...	...	...	...	...	68
58	...	...	...	1	...	3	14	14	15	11	6	5	4	...	2	...	...	...	...	...	...	...	53
60	...	1	...	1	...	5	10	7	12	10	8	8	2	2	1	...	...	...	...	...	...	...	75
62	...	...	...	1	1	2	1	7	4	7	6	4	3	3	1	4	1	2	...	...	...	...	67
64	...	...	...	...	...	...	3	...	5	5	4	2	1	1	4	1	1	...	...	...	...	...	45
66	...	...	...	...	...	2	...	2	...	1	2	1	6	2	1	1	...	...	...	...	...	...	28
68	...	...	...	...	...	...	1	1	...	1	4	2	3	1	2	...	3	1	...	...	...	...	18
70	...	...	...	...	...	...	...	...	...	2	1	3	2	2	2	...	...	2	1	1	...	...	19
72	...	...	...	...	...	...	...	...	...	...	...	2	1	2	1	1	0	...	1	0	...	1	16
74	...	...	...	...	...	...	1	...	...	1	...	1	...	...	2	...	...	...	...	...	...	...	9
76	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	...	1	...	1	...	...	...	5
78	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	4
80	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1	...	...	...	...	...	1
82	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1	1	...	...	...	2
84	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	3
Total	...	6	12	42	48	64	82	55	58	51	38	33	25	15	20	3	8	6	4	1	...	1	571

TABLE V.—*Correlation between width and length of tuber in the Early Ohio variety, grown at Northeast Experiment Station, Duluth, in 1919*

[Coefficient of correlation = 0.847 ± 0.025]

Width of tubers in millimeters.	Length of tubers in millimeters.																							Total.
	46	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	110	114	118	122	126	130	
44	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
46	...	1	2	...	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6
48	1	5	5	6	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	18
50	...	4	7	4	2	1	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	20
52	2	1	1	9	6	2	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	24
54	...	...	6	5	14	4	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	32
56	...	...	2	7	1	13	7	2	...	...	...	1	...	...	...	...	...	...	...	...	...	...	33
58	...	...	...	5	8	7	6	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	30
60	...	...	...	1	5	7	6	4	2	...	...	1	...	...	...	...	...	...	...	...	...	...	26
62	...	...	...	2	2	6	3	6	2	2	2	...	...	...	...	...	...	...	...	...	...	...	26
64	...	...	...	...	2	5	3	6	2	2	2	...	...	...	...	...	...	...	...	...	...	...	22
66	...	...	...	...	2	2	1	7	1	3	2	...	...	...	...	...	1	...	...	...	...	...	18
68	...	...	...	1	...	1	1	4	3	2	2	1	1	1	...	...	...	...	...	...	...	...	17
70	...	...	...	...	...	1	1	...	1	4	...	...	...	...	...	...	...	...	...	...	...	...	7
72	...	...	...	...	...	...	1	...	...	...	4	1	...	1	2	...	...	...	...	...	...	...	9
74	...	...	...	...	...	...	...	...	1	3	1	3	1	...	...	1	...	...	...	...	...	...	10
76	...	...	...	...	...	...	...	...	...	...	1	1	1	...	...	...	...	...	...	...	...	...	3
78	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1	...	...	...	...	...	2
80	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
82	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	...	...	...	...	...	2
84	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1	...	...	...	2
86	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	1
88	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1
90	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
92	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
Total	3	12	23	40	45	50	36	34	13	16	14	9	3	4	3	2	2	1	...	...	...	...	316

TABLE VI.—*Correlation between width and length of tuber in the early Ohio variety, grown on clay loam soil at Central Experiment Station, University Farm, St. Paul, in 1919*

[Coefficient of correlation 0.647±0.032]

Width of tubers in millimeters.	Length of tubers in millimeters.																							Total.
	46	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	110	114	118	122	126	130	134	
42				1	1			1																3
44				1	1	1	2	1	2															8
46				1	2	4	4	1	1	1														13
48			1	1	1	1	2	1		3														20
50				1		2	1	2	2		3	3	1											15
52				1	2	2			5	3	1	1	1											16
54				1				4		4	1	1	1											22
56			1						2	1	5	3	4	1	2	1								20
58					1					3	1	3		3										9
60									2	1	1	3	1			1	1	1						11
62							1			2	1	2	2			1	1	1						11
64												1		2	1			1						7
66											2			1										3
68												1	1		1									3
70										1														1
72														2										2
74														1			1							2
76													1											1
78																								
80													1											1
82																								
84																								
Total			2	6	8	10	11	11	15	22	14	19	8	8	6	3	3	2						148

TABLE VII.—*Correlation between width and length of tuber in the early Ohio variety, grown on sandy loam soil at Central Experiment Station, University Farm, St. Paul, in 1919*

[Coefficient of correlation 0.601±0.034]

Width of tubers in millimeters.	Length of tubers in millimeters.																							Total.
	46	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	110	114	118	122	126	130	134	
42	1					1		1																3
44					1	1	2			1														9
46					1	5	2	1	1	1	1													12
48					1	1	1	5	7	3	1		1											15
50						1	3	3	1	3	5		1											17
52							1	1	3	2	4	2	3	2										18
54				2				1		1	2	1	2	1										10
56								1	1	1	3	1	1	2	1	2	1							14
58							2	1		1	1	1	3	3	1	3		1	1					18
60									1		1	2			2	1								7
62												1		3	2	1	2	1						10
64										1	1					2		1						5
66												1	1			1		2		2		1		8
68																1		2						3
70													1					1	2	1				5
72																	1		1					2
74																		2						2
76														1										1
78																						1		1
80																								
82																					1			1
84																								
Total	1			2	2	8	13	17	9	13	20	10	13	12	6	11	4	10	4	3	1	2		161

TABLE VIII.—*Effect of growth conditions on the form of Early Ohio Tubers*

Lot No.	Place grown.	Year.	Form index ($\frac{\text{length}}{\text{width}}$) classes.							Total number of tubers.	Mean index.
			0.90	1.10	1.30	1.50	1.70	1.90	2.10		
2	Duluth	1919	14	110	38	2	1	....	....	165	1.14±0.01
2	University Farm sand loam	1919	....	1	3	17	25	13	1	60	1.65± .02
2	University Farm, clay loam	1919	....	13	17	30	44	10	1	105	1.59± .01
2	Grand Rapids	1919	....	22	67	39	12	1	....	141	1.36± .01
7	Grand Rapids	1919	....	15	67	30	11	1	....	124	1.36± .01
2	Grand Rapids	1920	1	28	38	4	....	....	....	71	1.23± .01
7	Grand Rapids	1920	1	14	30	1	....	....	....	45	1.23± .01

Table VIII shows the number of the lot, the place grown, the year, the frequency distribution according to the index of width to length, and the mean index for each lot. Early Ohio tubers grown at Duluth in 1919 were relatively short, very broad, and somewhat flattened, having a mean ratio of width to length of 1 to 1.14. An example of this form of tuber is shown in Plate 1, D, which shows the original form of lot 6 as obtained from Duluth in 1916. At University Farm, in 1919, on sandy loam soil the tubers were elongated, cylindrical in form, with a mean ratio of width to length of 1 to 1.65. On clay soil at University Farm the tubers were relatively thicker, broader, and shorter than those produced on the sand, having a ratio of width to length of 1 to 1.44. At Grand Rapids the tubers tended to be somewhat similar in form to those grown at Duluth but had less breadth and were slightly more elongated, having a mean ratio of width to length of 1 to 1.35 in 1919 and 1 to 1.23 in 1920. The difference in form obtained in 1919 and 1920 shows the effect of seasonal conditions on the form of tuber.

The results presented show that the mean index of the ratio of width to length of tubers can be used to detect changes in the form of tubers of the Early Ohio variety.

This method was used in 1919 and 1920 in ascertaining whether any difference in form of tubers existed between the lots of Early Ohio which were being tested. The results are presented in Table IX, which gives the number of the lots, the place and year grown, the frequency distribution according to their index number of width to length and the mean index number of each lot.

TABLE IX.—*Variation in form between different lots of Early Ohio potatoes in 1919 and 1920*

Lot No.	Place grown.	Year.	Form index (length/width) classes.						Total number of tubers.[1]	Mean index.
			0.90	1.10	1.30	1.50	1.70	1.90		
2	Grand Rapids	1919	....	22	67	39	12	1	141	1.36±.01
6	.....do	1919	2	58	103	59	7	....	229	1.31±.01
7	.....do	1919	....	15	67	30	11	1	124	1.36±.01
8	.....do	1919	1	28	69	37	4	1	140	1.33±.01
2	Duluth	1919	14	110	38	2	1	....	165	1.14±.01
7	.....do	1919	12	83	83	9	....	1	188	1.20±.01
9	Hopkins	1919	....	1	2	15	10	2	30	1.57±.02
2	Grand Rapids[1]	1920	1	28	38	4	....	....	71	1.23±.01
7	.....do[1]	1920	1	14	30	1	....	....	45	1.23±.01
9	.....do	1920	3	32	40	9	....	....	84	1.23±.01

[1] From seed stock grown at Duluth in 1919.

The mean of lots 2, 6, 7, and 8 grown at Grand Rapids in 1919 ranges from 1.31±0.01 to 1.36±0.01. The mean of lots 2 and 7 grown at Duluth in 1919 was 1.14±0.01 to 1.20±0.01, respectively. The difference between the lots at Grand Rapids is 3.5 times the probable error and between the two lots grown at Duluth 4.2 times the probable error. This would appear to be significant. That the difference is probably due to other causes than hereditary is indicated by the fact that lots 2 and 7, between which the greatest difference occurred when grown at Duluth, gave the same mean index, 1.36±0.01 at Grand Rapids, and when the portions of the lots grown at Duluth were tested out in 1920 at Grand Rapids they gave an identical mean index, 1.23±0.01. In 1920, lot 9 was obtained from a grower who had selected for a somewhat more elongated form of Early Ohio. The lot as obtained in the fall of 1919 gave a mean of 1.57±0.02. It was grown at Grand Rapids in 1920 in comparison with lots 2 and 7. The mean index obtained for the three lots was 1.23±0.01. The results of the four years' study on the form of tubers show that the six lots gave an identical reaction, as regards the form of the tuber, when grown under similar growth conditions. The mass selection practiced by the growers in lots 2 and 9 for 21 years had no demonstrable effect on the inheritable form of Early Ohio tubers. It was further found that the form of tubers was very distinctly influenced by the environmental conditions surrounding the development of the tubers. This influence was not found to be carried over in any detectable amount to the progeny. As has been pointed out, the environmental conditions which resulted in good or poor yields did not measureably affect the yield of the progeny. It is therefore evident that no correlation was found between the form of tubers and their yield.

EFFECT OF ENVIRONMENT ON OTHER CHARACTERS

The formation of knobs is an undesirable character. This fact has been so obvious to potato breeders that the expression of this character by seedlings resulted in their rejection, so that our commercial varieties do not form knobs when growth conditions are uniformly favorable

throughout the season. When growth conditions are such as to cause a second growth of the plant, the formation of knobs frequently occurs on the tubers of some varieties. In the original lots of Early Ohio secured in the spring of 1917 all were comparatively free of knobs except lot 8. Traces of knobs had formed on all but lot 2. The progeny of these lots when examined in the fall of 1917 were found to be similar for this character in all lots grown at the same place. Knobs were present to a greater or lesser degree on the tubers of the lots grown at Grand Rapids, University Farm, and Crookston. Those grown at Duluth were free of knobs. In 1918 all lots at University Farm produced knobs, while at Duluth, Grand Rapids, and Crookston potatoes were free of knobs. The six lots appeared to give a similar reaction in regard to the formation of knobs under similar environmental conditions.

Another undesirable character is the formation of fissures or crevices on the surface of the tubers. The tubers of the original lots of Early Ohio were free of these fissures. Tubers containing fissures were frequently found in all lots grown at University Farm in 1917 and 1918. In 1917 they were occasionally found in tubers of lots grown at Crookston. At no time were fissures found in tubers of lots grown at Duluth and Grand Rapids.

The depth of eyes and prominence of eyebrows were found to be similar for the progeny of all lots grown at the same place. Distinct differences in the expression of these characters were produced at the different places, but this difference in expression had no influence on the progeny, as the characters were again expressed according to the environmental conditions under which the tubers developed.

The surface of the skin of the Early Ohio tuber is covered with small corky dots or lenticels. De Vries (*23*) has shown that the lenticels on potato tubers are due to the growth of loose cells underneath the stomates, which push up through the stomates and rupture them. He pointed out that a prominent development of them could be secured by having the tuber under moist conditions. These dots either do not occur at all or are relatively inconspicuous on varieties belonging to the Rose group. The original lots differed in the number and prominence of these lenticels on the tubers. The lenticels were very prominent on the progeny of all lots grown at University Farm in 1917, slightly less prominent on those grown at Crookston, slightly prominent on those grown at Grand Rapids, and very inconspicuous on those grown at Duluth. The result was similar in 1918.

In the original seed stocks the tuber color was distinctly different for each lot. The difference did not reappear in the progeny of the lots when grown under similar conditions. The growth conditions at each place produced a characteristic color of tubers. At times there appeared to be a difference between lots grown at the same place, but no lot was consistently different from the others in this respect. There was always considerable variation between individual tubers of the same lot. In general the larger tubers appeared less colored than the smaller ones. The color in the tuber of this variety is in the tissue directly beneath the cells forming the outer skin. De Vries (*23*) called attention to the fact that in the last growth of the skin during the ripening period the skin, which is previously clear, transparent, and smooth becomes thick and opaque. In the lots of Early Ohio under observation the difference in the amount of color present may have been due

to the degree to which it was masked. The vines, especially at Duluth, Grand Rapids, and Crookston, were usually killed by frost before the ripening period was completed, so that the stage of maturity probably influenced the color appearance of the tuber. The type of soil at a particular place also had a noticeable effect on the skin, as, for instance, tubers grown in sandy loam soil at Grand Rapids possessed a flakiness of skin whereas those grown at Duluth on clay soil containing a plentiful supply of humus were extremely smooth. A similar smoothness was obtained on tubers of the same stock when grown on peat at the Coon Creek Peat Experimental Farm at Anoka. These and other factors which influence the texture and quality of the skin were probably the cause of some of the difference in the color of the tubers.

CONCLUSION

The lots of Early Ohio potatoes were, as far as could be ascertained, identical in their characteristics. The number of lots under observation was relatively small. It must, however, be considered that each lot was chosen because it offered a possibility of being a distinct strain. Furthermore, two of the seed stocks were known to have been separated from each other and from the other seed stocks studied for at least 20 years. As the Early Ohio originated approximately 50 years ago, 20 years would seem to be sufficient time to allow strains to develop within the seed stocks of a variety, if such a tendency existed. The selection practiced by the growers with divergent types in view should further have tended to bring out any differences that might have developed. Also the difference in environment was sufficiently great to bring out distinct differences in the expression of characters studied. If the environment had any tendency to influence the expression of the character in the progeny, its influence should have been apparent at the end of this period. The evidence presented indicates that the potato variety is relatively stable under vegetative propagation. While mutations are known to occur, they are apparently not sufficiently numerous to offer reasonable hope for the further improvement of varieties by asexual selection. This does not mean that the methods of asexual selection are of no value in the improvement of commercial seed stocks. The use of the individual-hill and tuber-unit methods of asexual selection in the seed plot aid in the elimination of varietal mixtures, and by separating the progeny of diseased and healthy tubers in the seed plot are of aid in the roguing out of diseased plants.

SUMMARY OF EXPERIMENTAL RESULTS

(1) Seven lots of Early Ohio potatoes representing difference in amount of selection practiced by growers and distinct regional types were obtained from growers at Anoka, Duluth, Grand Rapids, Glyndon, Hawley, Faribault, and Hopkins, Minn. Observations were made on the behavior of the lots in 1917, when grown in comparison with each other at University Farm, Duluth, Grand Rapids, and Crookston. In 1918 the lots were under observation at two or more places. On some lots observations were continued in 1919 and 1920.

(2) In 1917 there was a difference of 20 bushels per acre between the average yield at the four places of the highest yielding and lowest-yielding lot. No lot consistently gave either a high or low yield at more

than two places. Lot 6, the highest-yielding lot in 1917, gave the highest yield in 1918, but in 1919 it was outyielded by lot 2, the lowest-yielding lot in 1917. Lot 9, obtained in 1920, gave a yield almost identical with that of lot 2. Selection practiced by the growers on lots 2 and 9 had apparently no effect on increasing their productivity.

(3) The ratio of width to length of tuber was found to be a fairly good index by which differences in form could be detected in the Early Ohio variety. It furnished a mathematical expression by which the form of tubers grown under different conditions and during different seasons could be compared.

(4) The original lots differed in form. The most distinct differences were short, oval tubers, short, broad, flat tubers, elongated, cylindrical tubers, and distinct modifications of these three forms (see Pl. 1, A, B, D, C). When grown at University Farm, Duluth, Grand Rapids, and Crookston a distinct form which was the same for all lots was obtained at each place. At Grand Rapids it was shown that seasonal conditions affected the form. At University Farm, sandy loam and clay loam soil types produced distinct differences of form. No correlation between form and yield was observed.

(5) Knobs, fissures, prominence of lenticels, depth of eyes, prominence of eyebrows, and color of tubers were characters that were found to be unexpressed, expressed, or modified in their expression according to the environment under which the tubers developed. The expression of these characters on the tuber was not influenced by selection or by the environmental conditions surrounding the development of the seed stocks.

(6) Evidence presented shows that potato varieties do not run into definite strains, that they are relatively stable under vegetative propagation, and that the method of asexual selection does not offer reasonable hope for their further improvement.

LITERATURE CITED

(1) AITKEN, William.
1837. THE POTATO RESCUED FROM DISEASE AND RESTORED TO PRISTINE VIGOUR, BY A PLAN OF KEEPING AND CULTIVATION FOUNDED ON THE NATURAL PRINCIPLES OF THE VEGETABLE ECONOMY. Edinburgh and London. Original not seen. Review *in* Quart. Jour. Agr., v. 8, 1837/38, p. 84–96. 1838.

(2) APPEL, Otto.
1915. LEAF ROLL DISEASES OF THE POTATO. *In* Phytopathology, v. 5, no. 3, p. 139–148.

(3) CATHCART, Earl.
1884. ON THE CULTIVATED POTATO. *In* Jour. Roy. Agr. Soc. England, ser. 2, v. 20, p. 266–300, 2 fig.

(4) EAST, Edward.
1908. A STUDY OF THE FACTORS INFLUENCING THE IMPROVEMENT OF THE POTATO. Ill. Agr. Exp. Sta. Bul. 127, p. 375–456, 10 fig. Bibliography, p. 450–456.

(5) ——
1910. THE TRANSMISSION OF VARIATIONS IN THE POTATO IN ASEXUAL PRODUCTION. *In* Conn. Agr. Exp. Sta. 33d–34th Ann. Rpt., [1909]–10, p. 119–160, 5 pl. Literature cited, p. 140.

(6) EHRENBERG, Paul.
1904. DER ABBAU DER KARTOFFELN. *In* Landw. Jahrb., Bd. 33, p. 859–915, pl. 22–25. Bibliographical footnotes.

(7) GÜSSOW, H. T.
1918. OBSERVATIONS ON OBSCURE POTATO TROUBLES. I. HETERODERA RADICICOLA. *In* Phytopathology, v. 8, no. 9, p. 491–495, fig. 2–5.

(8) HUNTER, Alexander.
1803–04. GEORGICAL ESSAYS. 6 v., illus. York, England.
(9) KNIGHT, Thomas Andrew.
1920. ON RAISING NEW AND EARLY VARIETIES OF THE POTATO. *In* Trans. Hort. Soc. Lond., v. 1, ed. 3, p. 57–95 [i. e. 59].
(10) ———
1841. A SELECTION FROM THE PHYSIOLOGICAL AND HORTICULTURAL PAPERS, PUBLISHED IN THE TRANSACTIONS OF THE ROYAL AND HORTICULTURAL SOCIETIES... xii, 379 p., 3 fig., 8 pl. London.
(11) KRANTZ, F. A., and BISBY, G. R.
1921. THE RELATION OF MOSAIC TO RUNNING-OUT OF POTATOES IN MINNESOTA. Minn. Agr. Exp. Sta. Bul. 197, 31 p., 18 fig. References, p. 29–31.
(12) MARSHALL, [William].
1788. POTATOES. (*In* his Rural economy of Yorkshire... v. 2, p. 51–67. London.)
(13) MELHUS, I. E.
1917. NOTES ON MOSAIC SYMPTOMS ON IRISH POTATOES. (Abstract.) *In* Phytopathology, v. 7, no. 1, p. 71.
(14) MURPHY, Paul A.
1921. INVESTIGATION OF POTATO DISEASES. *In* Canada Exp. Farms Bul. 44, ser. 2, 86 p., 34 fig. Literature cited, p. 83–86.
(15) ORTON, W. A.
1914. POTATO WILT, LEAF-ROLL, AND RELATED DISEASES. U. S. Dept. Agr. Bul. 64, 48 p., 16 pl. Bibliography, p. 44–48.
(16) QUANJER, H. M.
1920. THE MOSAIC DISEASE OF THE SOLANACEAE, ITS RELATION TO THE PHLOEM-NECROSIS, AND ITS EFFECT UPON POTATO CULTURE. *In* Phytopathology, v. 10, no. 1, p. 35–47, 14 fig. Literature cited, p. 47.
(17) SHULTZ, E. S., and FOLSOM, Donald.
1920. TRANSMISSION OF THE MOSAIC DISEASE OF IRISH POTATOES. *In* Jour. Agr. Research, v. 19, no. 7, p. 315–338, pl. 49–56.
(18) ——— ——— HILDEBRANDT, F. Merrill, and HAWKINS, Lon A.
1919. INVESTIGATIONS ON THE MOSAIC DISEASE OF THE IRISH POTATO. Preliminary paper. *In* Jour. Agr. Research, v. 17, no. 6, p. 247–274, pl. A–B (col.), pl. 25–30. Literature cited, p. 272–273.
(19) STEPHENS, Henry.
1908–09. BOOK OF THE FARM DEALING EXHAUSTIVELY WITH EVERY BRANCH OF AGRICULTURE. 5th ed. rev. and largely rewritten by James Macdonald. 3 v. in 5, illus. Edinburgh and London.
(20) STEWART, F. C.
1916. OBSERVATIONS ON SOME DEGENERATE STRAINS OF POTATOES. N. Y. (Geneva). Agr. Exp. Sta. Bul. 422, p. 319–357, 12 pl.
(21) STUART, William.
1915. POTATO BREEDING AND SELECTION. U. S. Dept. Agr. Bul. 195, 35 p., 2 fig., 16 pl.
(22) SUTTON, Arthur W.
1898. THE POTATO. *In* Jour. Roy. Agr. Soc. England, ser. 3, v. 9, pt. 4, no. 36, p. 581–653, 58 fig., 1 fold. pl.
(23) VRIES, Hugo de.
1878. BEITRÄGE ZUR SPECIELLEN PHYSIOLOGIE LANDWIRTSCHAFTLICHER CULTURPFLANZEN. V. WACHSTHUMGESCHICHTE DER KARTOFFELPFLANZE. *In* Landw. Jahrb., Bd. 7, p. 591–682, pl. 16–17 (col.).
(24) WAID, C. W.
1907. RESULTS OF HILL SELECTION OF SEED POTATOES. *In* Amer. Breeders' Assoc. Rpt., v. 3, p. 191–198.
(25) WEBBER, H. J.
1908. PLANT-BREEDING FOR FARMERS. V. METHODS OF IMPROVING POTATOES. *In* N. Y. (Cornell) Agr. Exp. Sta. Bul. 251, p. 322–332, fig. 144. Some important books ... p. 331–332.
(26) WELLINGTON, R.
1920. THE USELESSNESS OF HILL SELECTION UNDER CONDITIONS WHERE RAPID DEGENERATION OR "RUNNING-OUT" IS PREVALENT. *In* Proc. Amer. Soc. Hort. Soc., 16th, 1919, p. 175–179.
(27) WHIPPLE, O. B.
1920. LINE-SELECTION WORK WITH POTATOES. *In* Jour. Agr. Research, v. 19, no. 11, p. 543–573.

(28) WHITE, Thomas H.
1918. FERTILIZING AND CULTURAL EXPERIMENTS WITH IRISH POTATOES. Md. Agr. Exp. Sta. Bul. 215, p. 151–174.

(29) WILSON, John H.
1907. EXPERIMENTS IN CROSSING POTATOES. *In* Trans. Highland and Agr. Soc. Scot., ser. 5, v. 19, p. 74–92, fig. 41–56.

(30) WORTLEY, E. J.
1918. POTATO LEAF ROLL: ITS DIAGNOSIS AND CAUSE. *In* Phytopathology, v. 8, no. 10, p. 507–529, 16 fig. Literature cited, p. 529.

PLATE 1

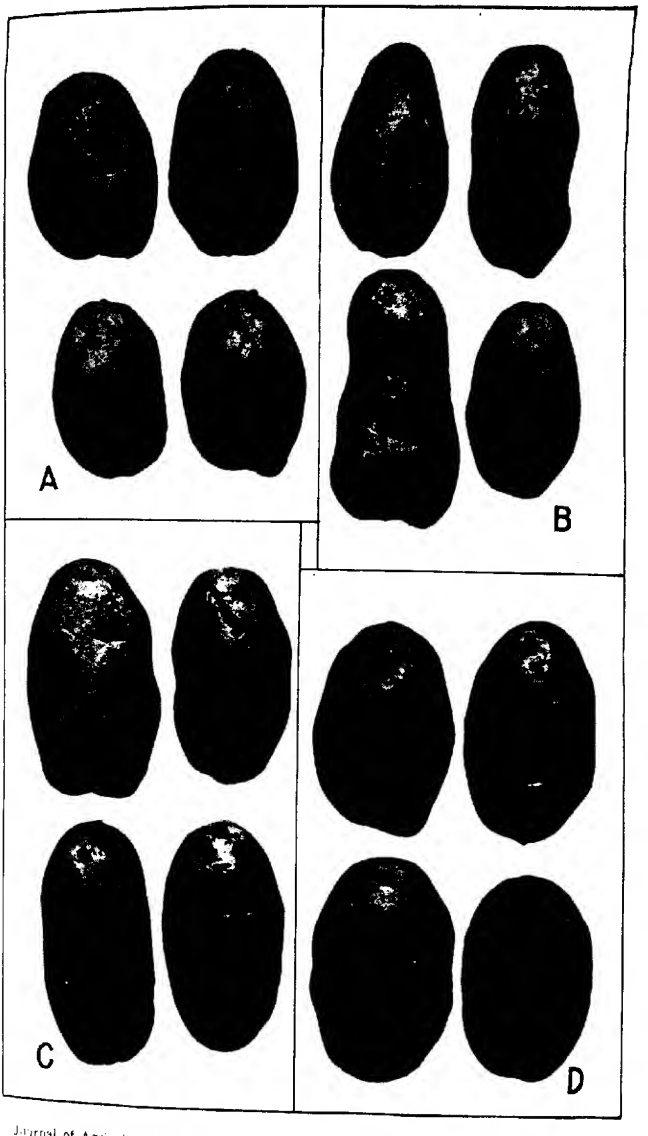
Potato tubers showing some of the variations existing between the original lots of Early Ohio. The progeny of these lots were found to be similar when grown under similar growth conditions.

A.—Short, oval, cylindrical tubers of lot 2 as obtained from Anoka in 1916.

B.—Somewhat elongated, irregular tubers of lot 4 as obtained from Faribault in 1916.

C.—Elongated, somewhat flattened tubers of lot 7 as obtained from the Red River Valley in 1916.

D.—Short, broad, flattened tubers of lot 6 as obtained from Duluth in 1916.


A
B
C
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ANATOMICAL STUDIES ON POTATO-WART[1]

By ERNST F. ARTSCHWAGER

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Considerable progress has been made in recent years in the study of the causal organism of potato-wart, but our knowledge of the anatomical structure of the tumor is still limited to brief accounts found in earlier publications. A study of the histology of the tumor, though primarily of interest to the anatomist, will indirectly advance other phases of research in connection with the wart disease.

The wart appears as a proliferation of meristematic regions of stem, stolon, and tuber. An examination of a partly mature plant, grown under conditions favorable for infection, will give a picture such as is presented in Plate 1. Warts are seen to have developed abundantly on all underground parts except the roots. The tumors vary in size from minute undifferentiated protuberances to intricate branch systems. The largest warts have developed on the underground stalk and terminally on stolons, while the smallest appear on tubers, usually as the result of belated infections.

The typical wart is nearly spherical in form and gives the impression of a solid structure with modified peripheral parts. These external modifications, however, are the visible external expression of deeply seated changes so intricate (Pl. 2, E) that only the aid of the microscope will reveal their component parts. The wart, indeed, consists fundamentally of depressed, antler-shaped branches or metamorphosed leaves, partly grown together and branching profusely near the periphery. Since the planes of branching change constantly, symmetrical expansion of all the component branches in a centripetal manner is impossible; as a result the parts are greatly malformed and bear but little resemblance to any normal organ of the plant.

When tuber infection is belated and conditions are generally unfavorable for the development of the parasite the growth of the wart comprises only a superficial modification of the parts attacked (Pl. 3, C, D). While this type of wart may be found on any diseased plant it constitutes the only type which is developed on semiresistant varieties.

Wart formation on aerial organs is uncommon, but occasionally stem buds close to the surface of the ground become infected. Since in these buds leaf differentiation has usually gone past the embryonic stage, even the stimulating effect of the parasite can not altogether change the subsequent development of these organs. The result is a malformed leaf with a lamina little expanded but thickened (Pl. 2, B).[2]

[1] Accepted for publication May 17, 1922.

[2] Mr. Freeman Weiss reports having found a small, roughly spherical wart originating from the midrib of the lower surface of a leaf 12 to 14 inches above the ground; it contained both resisting spores and sori in various stages of development.

The color of the wart below ground is that of the stolon and young tuber, commonly an ivory white. In varieties which produce highly colored tubers, like the Australian Blue, the color of the wart will also be that of the tuber. When developing above ground, the parts exposed to the sun develop chlorophyll and aid in assimilation. Toward the end of the growing season, or earlier, the warts show signs of decay. The color changes from white to a dark brown and finally to a dirty black. At the time the potatoes are ordinarily dug, most large warts have disintegrated, leaving only unsightly vestiges on the infected tubers. Small warts, according to Johnson(*6*),[3] may enter a dormant state and form the source for new infections the following season.

ANATOMY

A cross section of a young wart or of the peripheral part of an older one shows a centrally located vascular strand (Pl. 2, D) and a broad band of cortical tissue whose peripheral cells harbor the resting spores of the parasite (Pl. 4, B). The epidermis, where still intact, is composed of delicate cells isodiametric or with the longer axis in the radial direction. A periderm is not developed, although occasionally a shorter or longer band of cork cells is noticeable immediately below the zone of spore-containing cells, or may surround in concentric layers some deep seated resting spores. The walls of the cells containing the resting spores, as well as the neighboring cells, become lignified and suberized, and since the heavy walls of the resting spores undergo like changes, a lignin stain applied to a section of the wart makes the fungus infected area discernible to the naked eye and permits of ready differentiation with the aid of the microscope.

The cortical tissue (Pl. 5), which comprises by far the largest part of the wart, is composed of simple, large parenchyma cells. The cells are crowded with starch grains. Sugar is always present in varying amounts, and also tannins, primarily in newly infected regions, where, under the influence of the parasite, cellular activity is at its height. Other cell inclusions are more conspicuous by their absence. Calcium oxalate and protein crystals which are usually found in the peripheral region of the normal tuber are usually wanting. Protein crystals have been observed only in the outer cortical cells of the host—never in typical wart tissue.

Modifications of the normal type of storage cells of the wart are frequently observed and consist in their transformation into sclereids. They have been found abundantly in the aerial parts of the potato plant affected with blackleg (*2*) and normally in small numbers in the cortex of the underground stem and in the parenchyma tissue of dormant eyes.

The vascular tissue is centrally located, and only in transition regions is there found a siphonostele inclosing a large pith. The relative position of xylem and phloem is, at best, only approximate. Especially where the vascular elements are greatly reduced, the phloem and xylem appear independent of each other and with no definite orientation with respect to the axis of the organ. In small branches of the wart, however, phloem groups may be observed in close proximity to the xylem and may even surround it so completely as to give the effect of a typical amphicribral bundle. While the arrangement of the vascular tissue is certainly a departure from the normal type, it must be remembered that similar, if not identical, conditions exist in normal organs, such as the tuber (*1*).

[3] Reference is made by number (italic) to "Literature cited," p. 967.

The phloem groups abut directly on the cortex. There is no endodermis; and only groups of small-celled tissue, the homolog of a pericycle, may delimit the phloem from the storage tissue. The phloem groups are small and widely scattered; sometimes a sieve tube with a single cambiform cell may constitute an entire group. Often, however, the groups are larger and attain the size of the inner phloem of the tuber. The relative number of sieve tubes and parenchyma cells is approximately that found in the phloem of the underground organs and is small compared with the aerial parts. When stained with chlorozinciodid the side walls of the sieve tubes in contact with cortical cells show a network of fine, dark-staining bands inclosing areas of lighter color. Since there is an obvious need for rapid movement of food from the storage parenchyma to the growing region of the wart, the extensive pitting of the sieve tube with these storage cells appears as a functional adaptation; the converse relation, however, may also hold.

The xylem is composed of narrow, porous elements with secondary thickenings in the form of rings and close spirals. The end walls of the cells are chiefly oblique, being sometimes, however, strictly transverse. Since the course of the vascular tissue is very irregular and since branching and anastomosing takes place frequently, the xylem cells are commonly atypical. This diversity of form finds expression in abnormal wall sculpture, excessive slope of the end walls, and a general irregular form of the element as a whole. Typical fibers and pitted vessels are wanting. Narrow parenchymatous elements of variable length often separate the xylem from the cortex. Besides being smaller, these elements differ further from typical cortical cells in being devoid of starch. The walls of the xylem elements remain cellulose for a long period. This fact and the conspicuous absence of fibers and tracheids shows that the tissue is adapted primarily for conduction and not at all for support. Such qualitative reductions in vascular tissues are common in simple galls and appear to be adaptations for changes in function. Bally (3) believes that the adaptation in case of the wart is for water storage rather than for conduction. It might be questioned, however, whether conduction is second in importance to water storage in wart tissue; and may we not, from morphological considerations, expect only simple protoxylem elements in a tissue as simple, as well protected and as rapidly growing as that of the wart? Both xylem and phloem cells advance independently close to the peripheral region of the wart, a fact which further tends to emphasize the necessity for rapid movement of plastic materials as well as of water. Individual sieve tubes and protoxylem cells may be observed even in small warts, which makes it difficult to tell which of the vascular elements are differentiated first and whether phloem cells or xylem cells are more important in the early growth of the organ. Although normally elements that are essentially vascular rarely terminate a bundle, in the wart tissue individual sieve tubes and also ringed protoxylem cells have been observed to advance to the periphery of the organ unaccompanied by parenchyma cells.

The older basal part of the wart and more especially the transition region show a gradual approach to the normal structure. There is a steady increase in supporting tissue and improved provision for conduction of larger quantities of water. We may then expect to find fibers and pitted vessels in increasing numbers, and indeed we do. Withal there is a complete though gradual transition from the normal to the wart tissue, and although in its simplest form the wart shows both

qualitative and quantitative reduction of tissues, there exists, nevertheless, a marked similarity between structure of normal host and wart, and this is shown not only in similarity of position of the tissues with reference to each other but also in their practical identity as regards the essential composition of the vascular tissue.

MORPHOLOGICAL NATURE OF THE WART

From anatomical analysis the wart is a homoplastic growth with quantitative reduction in vascular tissue and increase in storage parenchyma. The likeness is even more marked and reaches a point of complete identity if we choose to compare reduced host tissue with transition regions in the wart. But even if we accept this conclusion, there still remains the answer to the question as to the nature of the wart in its entirety and its relation to the normal organs of the plant. To arrive at a satisfactory conclusion it will be necessary to follow briefly the early ontogeny of the wart and to consider the nature of the stimuli which initiate the abnormal growth.

A newly infected bud shows the surface covered with small pustules which in sectional view (Pl. 4, A) are found to consist of a small-celled tissue rich in protoplasm and very turgid. Certain of these protuberances show a slight depression with a brownish center in which is found a prosorus or summer sporangium of the parasite. These areas of new growth, according to Curtis (*4*) and Bally (*3*), have resulted from the stimulating effect of the fungus. Since the epidermal walls of these pustules are very delicate, and since new summer spores are formed and mature in rapid succession, new infections occur, and as a consequence new centers of growth are formed in direct proportion to the number of new infections. The finely adjusted stimulation which results in the formation of a progressively increasing area of meristematic tissue permits of an uninterrupted development of the parasite and the formation of large numbers of resting spores which under suitable conditions remain viable in the soil and form a latent source of infection for years to come.

In semiresistant varieties wart development remains superficial. The growth slightly resembles scab pustules, though the infected areas are somewhat more elevated (Pl. 3, C, D). In susceptible varieties, on the other hand, the warts are extensive structures (Pl. 2, A, D, C, E; 3 A, B) and only in their topography bear resemblance to the former kind. Percival (*8*) assumes that the wart is "a malformed branch system stimulated by the parasite to grow irregularly and before its natural time." A study of Plate 3, B, suggests no objection to such a theory, and a consideration of the anatomy of the vascular system seems only to lend additional support. However, granting that the stimulating effect of the fungus may result in a shortening or complete elimination of the rest period of the young bud, may we not expect a similar phenomenon in potato plants which are semiresistant to the wart? Yet this is not the case. Furthermore, an analogy with "witches'-broom" formation in Pteris (*5*) indicates that it may be unessential, however, to presuppose the existence of buds in order to initiate growth of extensive though somewhat abnormal foliar organs; that, in fact, the stimulus exerted by the fungus is sufficient to bring about cell division and initiate organ formation in meristematic regions of plants. In the potato, too, extensive wart formation often results from the infection of an outer bud scale which has normally completed development. The association

of the fungus with reactive host cells is sufficient to initiate new growth. But the same parasite in the subsequent development of the new organ acts as inhibitor and modifier and thus alters the appearance of the new structure completely. Early developmental studies and the comparative ease with which the pathogene is identified have left no doubt that the wart, as a whole, is normal host tissue and that only the peripheral regions contain typical traumatic cells. An analogous case is presented by Dr. E. F. Smith (*9*). The growth resulting from inoculation is composed of normal host tissue and not of parasitized cells, as viewed by Levine (7). The present impossibility of demonstrating the crowngall pathogene in the tissues, however, gives only presumptive evidence, but a consideration of the reaction of host and parasite in case of the wart of potato should give, if analogy be worth anything, a strong support to the theory defended by Doctor Smith.

The wart can be considered a foliar branch system. The existence of various types of warts seems to be bound up with the relative susceptibility of the host, the nature and extent of the primary infection, and such factors as tend to modify plant growth in general.

LITERATURE CITED

(1) ARTSCHWAGER, Ernst F.
1918. ANATOMY OF THE POTATO PLANT, WITH SPECIAL REFERENCE TO THE ONTOGENY OF THE VASCULAR SYSTEM. *In* Jour. Agr. Research, v. 14, p. 221–252, 4 fig., pl. 27–47. Literature cited, p. 251–252.

(2) ———
1920. PATHOLOGICAL ANATOMY OF POTATO BLACKLEG. *In* Jour. Agr. Research, v. 20, p. 325–330, 1 fig., pl. 57–58. Literature cited, p. 330.

(3) BALLY, Walter.
1911. CYTOLOGISCHE STUDIEN AN CHYTRIDINEEN. *In* Jahrb. Wiss. Bot. [Pringsheim], Bd. 50, p. 95–156, 6 fig., pl. 1–5.

(4) CURTIS, K. M.
1921. THE LIFE-HISTORY AND CYTOLOGY OF SYNCHYTRIUM ENDOBIOTICUM (SCHILB.), PERC., THE CAUSE OF WART DISEASE IN POTATO. *In* Phil. Trans. Roy. Soc. London, ser. B., v. 210, p. 409–478, 1 fig., pl. 12–16. Literature, p. 462–464.

(5) GIESENHAGEN, K.
1892. UEBER HEXENBESEN AN TROPISCHEN FARNEN. *In* Flora, Bd. 76, p. 130–156, pl. 12–13.

(6) JOHNSON, Thomas.
1909. CHRYSOPHLYCTIS ENDOBIOTICA, SCHILB. (POTATO-WART OR BLACK SCAB), AND OTHER CHYTRIDIACEAE. *In* Sci. Proc. Roy. Dublin Soc., v. 12, p. 131–144, pl. 9–11. List of authorities quoted in the text, p. 144.

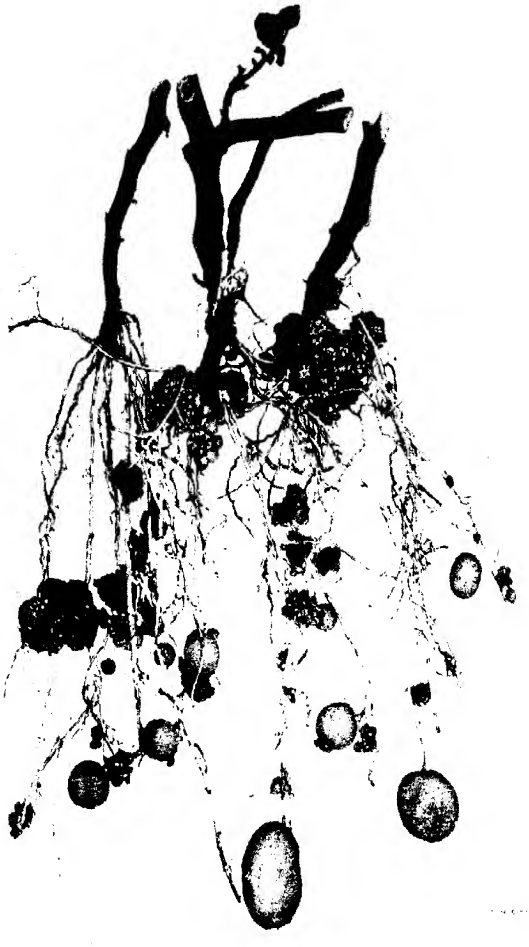
(7) LEVINE, Michael.
1919. STUDIES ON PLANT CANCERS. I. THE MECHANISM OF THE FORMATION OF THE LEAFY CROWN GALL. *In* Torrey Bot. Club, v. 46, p. 447–452, pl. 17–18.

(8) PERCIVAL, John.
1909. POTATO-WART DISEASE: THE LIFE HISTORY AND CYTOLOGY OF SYNCHYTRIUM ENDOBIOTICUM (SCHILB.) PERCL. *In* Centbl. Bakt. [etc.] Bd. 25, p. 440–447, 3 pl. Literature, p. 445–446.

(9) SMITH, Erwin F.
1921. EFFECT OF CROWNGALL INOCULATIONS ON BRYOPHYLLUM. *In* Jour. Agr. Research, v. 21, p. 593–598, pl. 101–110.

PLATE 1

Color photograph showing wart infection on underground stalk, stolons, and tubers. (Photograph by Freeman Weiss.)



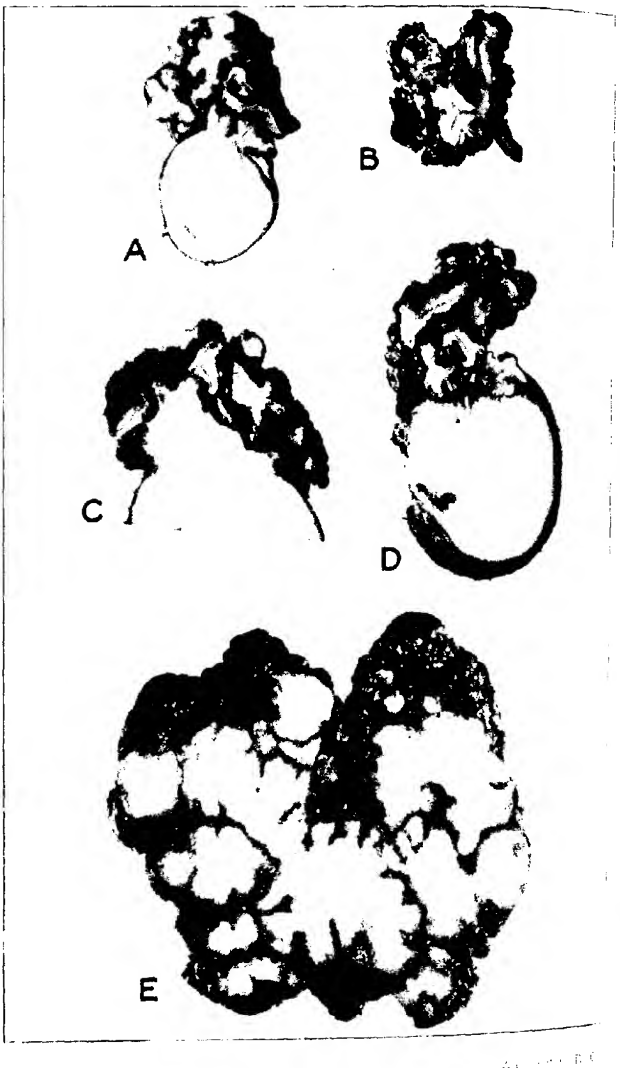

A
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PLATE 2

A.—Sectional view of large wart developed from terminal bud of tuber.

B.—Sectional view of aerial wart. Note general appearance of wart and central location of vascular tissue.

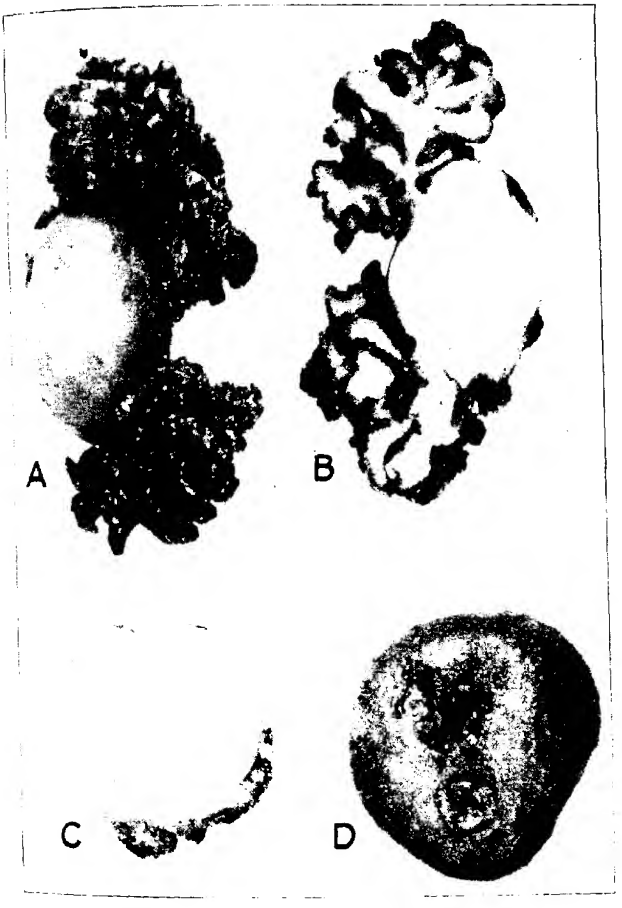
C.—Sectional view of large wart on tuber. The vascular tissue shows the arrangement which is typical of petiolar or midrib bundles.

D.—Sectional view of large wart on tuber. The apparent solid structure is an aggregate of compressed, modified leaves.

E.—Sectional view of large wart on stolon. The branching is often so intricate that only the aid of the microscope will reveal the component parts.

PLATE 3

A.—Surface view of large wart on tuber.
B.—Sectional view of the same wart, showing characteristic branching.
C.—Sectional view of wart on a semiresistant variety.
D.—Surface view of the same wart.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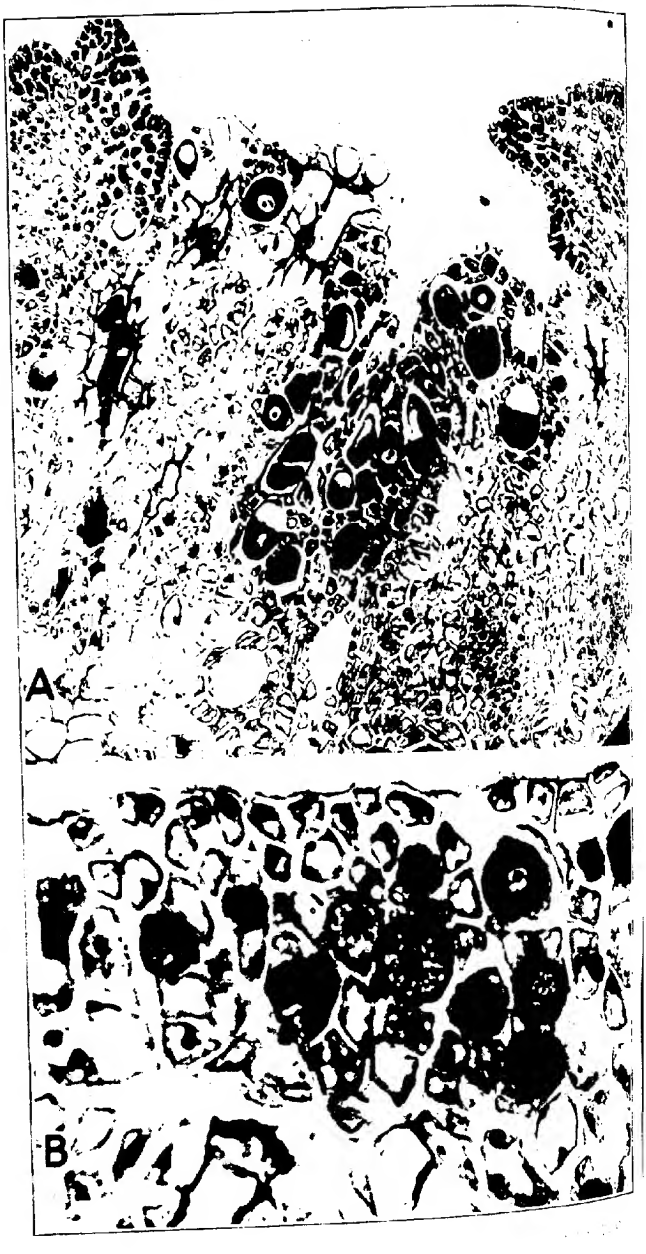
A
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PLATE 4

A.—Section through the peripheral region of young wart, showing resting spores, summer sori, and new centers of growth which have resulted from the stimulating effect of the parasite.

B.—Section though an older part of a wart, showing structure and position of resting spores.

PLATE 5

Section of young wart, showing general appearance of tissues and location of spore-bearing cells.

PLATE 5

INFLUENCE OF TEMPERATURE AND EVAPORATION UPON THE DEVELOPMENT OF APHIS POMI DEGEER[1]

By FRANK H. LATHROP [2]

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INTRODUCTION

Entomologists attacking economic problems are ever impressed with the need of a more thorough knowledge of the influence of the environmental factors which control the activities of the insects under investigation. The interrelations between insects and their environment are highly complex, and attempts at their determination are fraught with many difficulties. That any effort in this direction is well worthy of the expense in time and energy there can be little doubt, for, while this is as yet a comparatively unexplored field, there are many instances of the application of a knowledge of environmental factors to the applied control of economic pests. Headlee [3] pointed out the possibilities of the reduction of certain stored grain pests by modifying the relative humidity of the air within the container. Lovett and Fulton,[4] in discussing the control of the codling moth in the Willamette Valley, state:

> Where the evening temperature during May at 8:00 p. m. is 60° or above, the first generation codling moths may be expected to deposit eggs. Consequently when this temperature of 60° at 8:00 p. m. is registered, it is the proper time to apply the "thirty-day" codling moth spray.

A realization of the economic bearing of such information prompted the writer to make observations of certain climatic factors in connection with a study of the activities of several species of apple aphids, a group of insects which seem especially susceptible to climatic influence. A considerable amount of data on evaporation, temperature, and precipitation has been collected which, aside from the bearing upon the present study, should be of considerable general interest to both plant and animal ecologists.

In order to concentrate the study and to avoid scattering the data over too broad a field, observations in this connection were practically limited to a single species *Aphis pomi* DeGeer.

An understanding of the fundamentals of the life history of the species is desirable in considering the data here presented. For this reason the seasonal cycle is briefly reviewed.

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[1] Accepted for publication Jan. 16, 1922.

[2] The writer is indebted to Prof. A. L. Lovett for encouragement in the prosecution of this study, and to Mr. Richard Jones whose painstaking work as Technician in the Department of Entomology relieved the writer of much of the routine work of this study.

[3] HEADLEE, Thomas J. SOME FACTS RELATIVE TO THE INFLUENCE OF ATMOSPHERIC HUMIDITY ON INSECT METABOLISM. *In* Jour. Econ. Ent., v. 10, no. 1, p. 31-38. 1917.

[4] LOVETT, A. L., and FULTON, B. B. FRUIT GROWER'S HANDBOOK OF APPLE AND PEAR INSECTS. Oreg. Agr. Exp. Sta. Circ. 22, p. 8. 1920.

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Washington, D. C.

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Mar. 24, 1923
Key No. Oreg.-8

LIFE HISTORY OF APHIS POMI

The green apple aphis passes the winter in the egg stage. The eggs are placed on the bark of the water sprouts and other terminal growths of apple and frequently occur grouped in immense numbers. With the unfolding of the buds in the spring, these eggs hatch, and the tiny nymphs migrate to the newly developed foliage.

These "stem mothers" and the succeeding generations feed upon the succulent foliage of apple throughout the summer. There is no migration to alternate food plants as there is with many species of aphids, and the winged forms which are produced serve merely to disseminate the species.

Reproduction throughout spring and summer is entirely viviparous and parthenogenetic. With the approach of fall, males and oviparous females are produced, and the over-wintering eggs are deposited.

There are a variable number of generations during the season, depending upon environmental conditions.

METHODS EMPLOYED

This work has been entirely in the nature of a field study, and no attempt was made to modify or control the conditions of temperature or moisture.

The experimental plot was located on the college farm at Corvallis, Oreg., about one mile from the Agricultural Building and had an elevation of approximately 225 feet above sea level. This plot consisted of 1- and 2-year-old Greening apple trees planted in two rows about 4 feet apart with the trees about 3 feet apart in the rows. To the westward about 60 to 75 feet distant there was a dense growth of alders along the banks of Oak Creek. These trees, being some 35 feet in height, served to break the force of the strong, westerly "sea breezes" prevalent during the summer months.

As the aphid eggs hatched, numbers of the nymphs were transferred to suitable buds on the experimental trees and here allowed to mature. In obtaining nymphs of the later generations, a number of adults would be placed on a suitable aphis-free leaf cluster. The following day these adults were removed, and the nymphs born during the 24-hour period were allowed to remain. These nymphs were permitted to mature in order to obtain the length of the developmental period. The developmental period was reckoned from the day after birth till the day of the appearance of the first young, inclusive.

The trees upon which the experiments were being conducted were protected by a special type of cage (fig. 1). This consisted of a cylinder of galvanized wire cloth, open at one end. To the open end of this cage was attached a cheesecloth skirt. The cage was inverted over the tree, and held in position at the proper height by means of a stake set near by. The cheesecloth skirt was gathered about the trunk of the tree and tied with a cord. A band of cotton batting placed at the proper height on the tree rendered a perfect fit between the cloth skirt and the tree, and prevented binding of the trunk from the tie-cord. This type of cage is easily removed for examination of the aphids, is as readily replaced, and has proved quite satisfactory for this work.

The evaporation records were obtained by means of a "nonabsorbing" evaporimeter or atmometer (fig. 2) similar to instruments used in many evaporation studies by various workers during recent years. Standardized, spherical, porous, porcelain cups were obtained from the "Plant

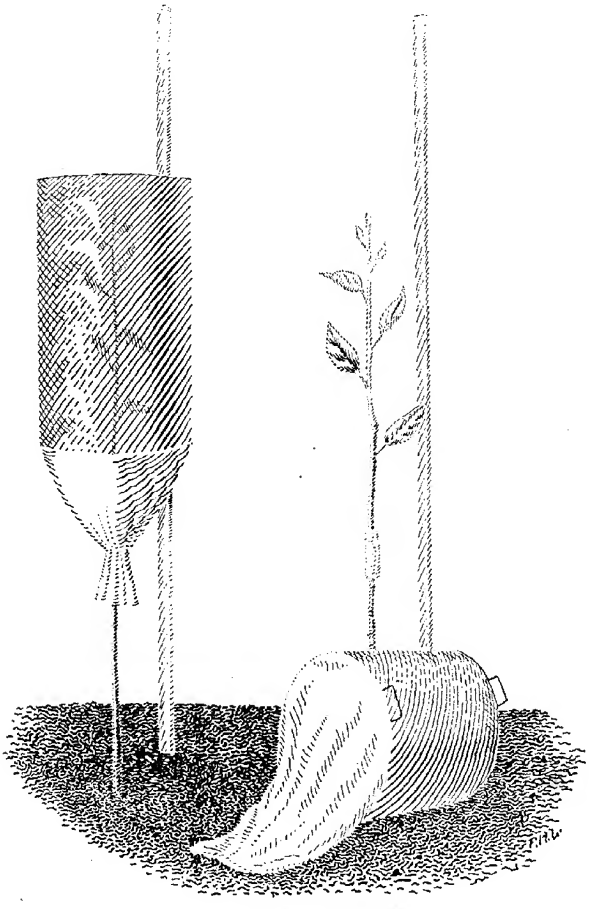

FIG. 1.—Cage used in rearing aphids.

World," and results as here given should be comparable with results obtained elsewhere [5] by means of similar instruments.

Observations were made daily at 9.30 a. m. The amount of evaporation was determined by filling the evaporimeter at this time.

[5] LIVINGSTON, Burton Edward. ATMOSPHERIC INFLUENCE ON EVAPORATION AND ITS DIRECT MEASUREMENT. In Mo. Weather Rev., v. 43, no. 3, p. 126–131, 2 fig. 1915. References and notes, p. 131.

A graduated pipette was used and readings were made to tenths of cubic centimeters.

Temperature records were obtained by means of a Tycos Dial Type Mercury Recording Thermometer, manufactured by Taylor Instrument

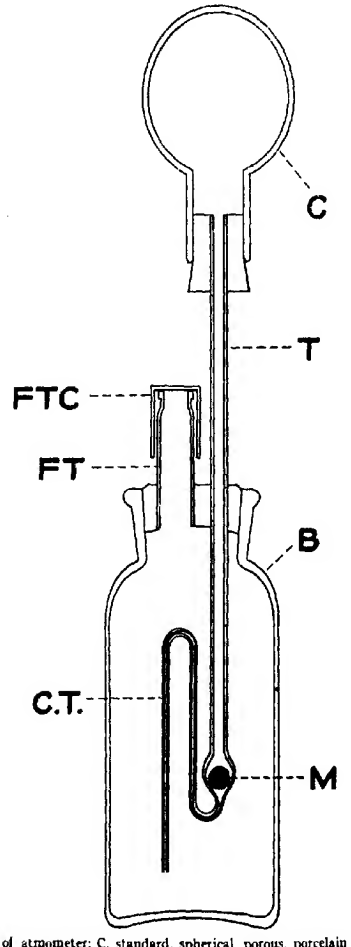

FIG. 2.—Sectional view of atmometer: C, standard, spherical, porous, porcelain cup; T, water supply tube; B, water bottle; FT, filling tube; FTC, filling tube cover; M, mercury drop to prevent return of water from cup; CT, capillary tube.

Companies, Rochester, N. Y. The daily mean temperature was calculated by reading the temperatures on the charts for each half hour and averaging these 48 readings. The mean temperature for any given period of days was obtained by averaging the daily mean temperatures.

[1] For the records of precipitation, the writer is indebted to the Department of Soils of the Oregon Agricultural Experiment Station. Observations on precipitation were made daily at 5.00 p. m. and hence are not exactly comparable with the temperature and evaporation records as given in this paper.

TABLE I.—*Daily evaporation and precipitation, 1919, at Corvallis, Oreg.*

Date.	Evaporation.	Precipitation.	Character of weather.
	Cc.	*Inches.*	
Mar. 31	22.5	0	
Apr. 1	11.2	0	Cloudy.
2	.....	0	do.
3	13.0	0.15	do.
4	5.7	.65	do.
5	7.0	.57	do.
6	8.0	.04	do.
7	10.3	0	Partly cloudy.
8	12.7	0	do.
9	.....	0	do.
10	24.0	.20	do.
11	.....	.08	
12	24.0	0	
13	13.8	.12	do.
14	18.8	0	
15	14.9	0	
16	1.7	.12	Cloudy.
17	4.1	.71	do.
18	6.5	.47	do.
19	.....	.15	do.
20	18.7	.10	Partly cloudy.
21	.....	0	
22	34.2	0	
23	14.9	0	
24	12.2	T.	do.
25	8.4	.07	do.
26	.....	0	
27	31.8	0	
28	18.4	0	
29	26.4	0	
30	34.6	0	
May 1	19.7	0	
2	17.9	0	do.
3	.....	0	
4	91.7	0	
5	35.6	0	
6	39.1	0	
7	26.1	0	
8	17.7	0	do.
9	20.2	0	do.
10	.....	0	do.
11	24.7	.11	do.
12	9.1	.10	do.
13	24.6		
14	8.8	.05	do.
15	7.9	.05	Cloudy.
16	5.3	.22	do.
17	.....	0	do.
18	21.4	0.03	do.
19	21.4	0	
20	31.0	0	
May 21	.....	0	
22	49.1	0	
23	22.8	0	
24	.....	0	Partly cloudy.
25	16.4	.55	Cloudy.
26	13.3	0	Do.
27	14.7	0	Do.
28	18.0	0	Do.
29	9.3	.15	Partly cloudy.
30	16.1	.06	Do.
31	.....	0	
June 1	61.4	0	
2	27.7	0	
3	34.0	0	
4	45.6	0	
5	31.3	0	
6	30.3	0	
7	.....	0	
8	58.7	0	
9	14.0	.02	
10	10.9	0	Do.
11	13.7	0	Do.
12	12.9	0	Do.
13	9.5	.08	
14	16.3	0	Do.
15	12.3	.02	
16	18.5	0	Do.
17	28.6	0	
18	27.9	0	
19	23.2	0	Do.
20	15.4	0	Do.
21	21.3	0	Do.
22	17.2	0	Do.
23	27.2	0	
24	29.4	0	
25	30.9	0	
26	8.8	.10	
27	21.9	0	Do.
28	17.0	0	Cloudy.
29	29.5	0	
30	24.7	0	
July 1	25.6	0	
2	33.5	0	
3	39.1	0	
4	28.4	0	
5	20.2	0	Partly cloudy.
6	16.9	0	Do.
7	38.7	0	
8	47.3	0	
9	41.6	0	Do.
10	22.0	0.2	

TABLE I.—*Daily evaporation and precipitation, 1919, at Corvallis, Oreg.*—Continued

Date.	Evaporation.	Precipitation.	Character of weather.
	Cc.	*Inches.*	
May 11	18.4	0	do.
12	36.5	0	
13	52.4	0	
14	44.2	0	
15	32.5	0	
16	34.8	0	
17	35.5	0	
18	40.2	0	
19	51.3	0	
20	47.5	0	
21	54.0	0	
22	58.5	0	
23	17.5	.08	
24	23.9	0	do.
25	16.3	0	
26	.....	0	
27	54.0	0	
28	22.4	0	
29	9.0	0	Cloudy.
30	20.5	0	Partly cloudy.
31	15.9	0	do.
Aug. 1	14.9	0	do.
2	11.3	0	do.
3	9.0	0	do.
4	14.6	0	do.
5	31.5	0	do.
6	27.3	0	do.
7	17.9	0	do.
8	25.0	0	
9	33.5	0	
10	34.1	0	
11	18.0	.05	Partly cloudy.
12	16.1	0	do.
13	36.5	0	
14	59.0	0	
15	47.3	0	
16	21.7	0	
17	13.9	0	do.
18	25.5	0	
19	34.6	0	
20	34.2	0	
Aug. 21	32.3	0	
22	35.8	0	
23	39.2	0	
24	32.5	0	
25	28.7	0	
26	18.3	0	Partly cloudy.
27	31.3	0	
28	39.1	0	
29	28.7	0	
30	15.6	0	Do.
31	11.7	.09	Do.
Sept. 1	29.8	0	
2	22.0	0	
3	3.9	T.	Do.
4	3.1	.40	Cloudy.
5	0.7	.70	Do.
6	.....	.25	Do.
7	7.8	.01	Partly cloudy.
8	0.6	.25	Cloudy.
9	8.7	0	Partly cloudy.
10	13.9	0	
11	2.7	.40	Cloudy.
12	22.0	0	
13	46.0	0	
14	27.8	0	
15	16.1	0	Do.
16	6.5	0	Do.
17	10.9	0	Do.
18	19.4	0	
19	17.6	0	
20	28.2	0	
21	78.6	0	
22	43.8	0	
23	28.8	0	
24	22.3	0	
25	19.8	0	
26	17.0	0	
27	.....	.12	Do.
28	19.7	.4	
29	.....	0	
30	6.3	.55	Do.

TABLE II.—*Daily temperature, evaporation, and precipitation at Corvallis, Oreg., 1920*

Date.	Temperature.			Evaporation.	Precipitation.	Character of weather.
	Minimum.	Mean.	Maximum.			
	° *F.*	° *F.*	° *F.*	*Cc.*	*Inches.*	
Mar. 29.....	35	45.6	58	12.6	0	
30.....	24	34.0	48	7.1	0.50	Cloudy.
31.....	33	38.6	47	5.9	.32	Do.
Apr. 1.....	39	41.8	46	10.2	.20	Do.
2.....	34	41.1	51	20.4	0	Partly cloudy.
3.....	45	48.2	62	.....	.04	Cloudy.
4.....	44	49.4	62	23.0	.03	Partly cloudy.

TABLE II.—*Daily temperature, evaporation, and precipitation at Corvallis, Oreg., 1920*—Continued

Date.	Temperature.			Evaporation.	Precipitation.	Character of weather.
	Minimum.	Mean.	Maximum.			
	°F.	°F.	°F.	*Cc.*	*Inches.*	
Apr. 5	36	44.2	56	.....	0.08	
6	44	47.3	55	32.2	.03	Cloudy.
7	33	41.5	54	9.2	.08	Do.
8	32	40.2	50	3.6	.58	Cloudy.
9	40	44.3	55	.....	.10	Do.
10	29	45.6	60	.....	.10	
11	42	50.6	65	33.6	0	
12	37	45.2	54	3.3	.12	
13	37	43.7	56	7.9	.11	Partly cloudy.
14	41	45.5	56	6.7	.35	Cloudy.
15	29	41.9	56	12.4	.10	
16	30	42.4	52	12.3	.05	Partly cloudy.
17	27	42.7	56	.....	.01	
18	42	51.1	64	27.9	0	
19	30	39.7	50	7.9	.24	Cloudy.
20	28	39.0	48	6.0	.11	Partly cloudy.
21	30	39.0	52	5.2	.06	Do.
22	26	39.9	57	.....	.09	Do.
23	28	43.9	59	19.5	0	
24	31	49.2	63	.....	0	
25	32	54.8	70	42.2	0	
26	36	57.5	78	26.3	0	
27	39	51.7	68	.....	0	
28	40	48.5	65	38.3	0	
29	38	46.3	55	13.7	0	
30	37	46.5	59	15.2	.01	
May 1	36	46.1	60	.....	0	
2	30	47.5	62	34.0	0	
3	30	48.4	64	17.3	0	
4	31	49.3	64	19.1	0	
5	33	52.6	69	19.0	0	
6	37	58.5	79	24.4	0	
7	46	56.7	78	22.4	0	
8	40	53.0	69	.....	.03	
9	27	46.9	66	45.0	0	
10	28	46.6	64	20.8	0	
11	30	48.0	64	21.8	0	
12	30	50.3	68	25.9	0	
13	28	49.0	69	24.3	0	
14	38	55.9	72	33.9	0	
15	35	55.1	73	.....	0	
16	50	61.6	80	56.4	0	
17	37	53.5	70	15.9	.23	
18	31	51.5	74	24.2	0	
19	35	52.2	70	25.1	0	
20	34	48.9	66	11.9	0	
21	27	47.5	64	20.4	0	
22	42	52.1	65	.....	0	Do.
23	34	48.1	65	33.6	0	Do.
24	25	42.8	59	13.2	0	
25	32	50.9	66	21.5	0	Do.
26	37	52.1	68	15.5	0	
27	34	50.1	69	20.0	.17	
28	34	49.6	68	17.8	.01	Do.
29	26	44.3	61	.....	.05	
30	28	47.0	64	31.3	.02	
31	30	52.7	70	31.7	0	
June 1	35	58.4	78	40.2	0	
2	44	64.1	85	39.1	0	

TABLE II.—*Daily temperature, evaporation, and precipitation at Corvallis, Oreg., 1920*—Continued

Date.	Temperature.			Evaporation.	Precipitation.	Character of weather.
	Minimum.	Mean.	Maximum.			
	° F.	° F.	° F.	*Cc.*	*Inches.*	
June 3	47	63.3	88	44.6	0	
4	42	58.6	79	24.7	0	
5	45	58.4	75	.....	0	
6	51	53.5	63	23.4	.10	Cloudy.
7	45	52.0	58	5.1	.41	
8	37	52.4	69	12.7	.39	Partly cloudy.
9	38	53.5	72	21.9	0	
10	50	55.5	66	10.5	0	Cloudy.
11	45	54.6	66	16.9	.03	Partly cloudy.
12	49	57.4	74	.....	0	
13	54	57.5	62	20.1	.20	Cloudy.
14	44	55.8	67	22.3	.53	Partly cloudy.
15	36	52.0	68	15.2	0	Do.
16	52	58.2	72	14.1	0	Do.
17	38	54.5	71	20.0	.19	Do.
18	39	56.8	71	27.6	0	
19	44	63.2	80	.....	0	
20	46	64.5	84	70.1	0	
21	46	59.9	82	28.8	0	
22	33	52.9	62	17.2	0	
23	35	52.2	68	26.6	0	Do.
24	42	53.0	70	16.6	0	
25	39	52.7	67	18.2	0	
26	45	62.4	78	.....	0	
27	47	64.7	82	69.6	0	
28	44	64.7	84	26.9	0	
29	49	67.7	89	34.2	0	Do.
30	43	65.3	88	28.8	0	
July 1	45	67.1	88	38.6	0	
2	46	67.3	90	43.3	0	
3	38	58.1	80	.....	0	
4	36	59.8	82	.....	0	
5	39	62.4	84	93.5	0	
6	48	68.5	89	36.5	0	
7	50	68.1	93	38.7	0	
8	43	60.0	78	23.4	0	
9	39	63.1	85	28.7	0	
10	49	60.6	80	.....	0	
11	50	57.2	68	39.9	0	Cloudy.
12	51	56.0	66	7.7	0	Do.
13	52	57.0	62	5.2	.41	
14	48	60.8	76	9.2	Trace	
15	49	64.8	86	22.8	0	Do.
16	56	64.7	88	23.7	0	Do.
17	45	63.5	81	.....	0	Do.
18	53	64.4	81	58.2	0	Partly cloudy.
19	50	61.2	74	17.9	0	Do.
20	50	64.1	82	25.0	0	
21	41	59.2	78	21.2	0	
22	41	62.9	82	30.2	0	
23	42	60.9	80	28.6	0	
24	40	59.4	77	.....	0	
25	40	63.4	84	65.8	0	
26	49	67.9	88	36.4	0	
27	54	66.0	84	35.7	0	
28	56	60.6	70	12.8	0	Cloudy.
29	40	57.6	70	13.8	0	Do.

TABLE II.—*Daily temperature, evaporation, and precipitation at Corvallis, Oreg., 1920*—Continued.

Date.	Temperature.			Evaporation.	Precipitation.	Character of weather.
	Minimum.	Mean.	Maximum.			
	°F.	°F	°F	Cc.	*Inches.*	
July 30	44	63.8	83	26.3	0	
31	40	61.9	80	.....	0	
Aug. 1	46	64.9	87	63.0	0	
2	45	63.8	84	28.5	0	
3	46	66.6	82	36.3	0	
4	54	69.4	89	36.6	0	
5	53	66.4	84	21.6	0	
6	47	65.8	88	27.7	.05	Cloudy.
7	59	71.6	88	.....	0	
8	56	65.6	82	53.3	0	
9	45	63.7	82	27.6	0	
10	48	67.2	88	30.9	0	
11	50	74.5	92	50.9	0	
12	53	76.9	100	49.5	0	
13	47	74.5	100	40.9	0	
14	43	68.4	97	.....	0	
15	45	67.2	93	72.9	0	
16	40	61.6	86	32.1	0	
17	32	54.0	75	23.7	0	
18	42	58.4	76	29.6	0	
19	41	67.6	88	47.4	0	
20	42	67.6	96	36.4	0	
21	46	67.0	94	.....	0	
22	42	60.7	85	52.4	0	
23	56	67.9	87	33.3	0	
24	48	61.3	77	22.6	0	Do.
25	36	51.9	70	.....	.01	Do.
26	43	58.0	76	32.5	0	
27	40	50.7	64	3.8	.22	Do.
28	51	57.8	74	.....	.02	Do.
29	30	48.2	67	27.9	.49	Do.
30	37	54.9	74	23.0	0	
31	40	65.3	85	46.4	0	
Sept. 1	41	64.6	90	32.4	0	
2	40	62.1	87	24.3	0	
3	40	58.9	82	20.1	0	
4	50	60.6	78	.....	0	
5	33	53.3	71	33.9	0	
6	32	51.4	70	19.7	0	
7	41	55.4	74	16.3	0	
8	47	53.3	62	9.7	0	Do.
9	48	51.5	58	5.0	.08	Do.
10	52	56.4	60	3.3	.23	Do.
11	49	56.9	69	.....	.01	Do.
12	48	54.2	68	14.2	1.18	Partly cloudy.
13	44	50.5	58	1.7	.95	Cloudy.
14	37	50.9	69	9.6	.26	Partly cloudy.
15	41	55.7	75	15.2	0	

EVAPORATION STUDIES

During the summer of 1919 a series of experiments was conducted in the hope that the measurement of atmospheric evaporation—combining, as it does, effects of both temperature and humidity—might, under normal outdoor conditions, give a fairly accurate index to the rate of metabolism of *Aphis pomi*. The study was continued during the summer of 1920.

The daily evaporation rates during the periods covered by these investigations are given in Tables I and II and are shown graphically in figures 3, 4, 5, and 6.

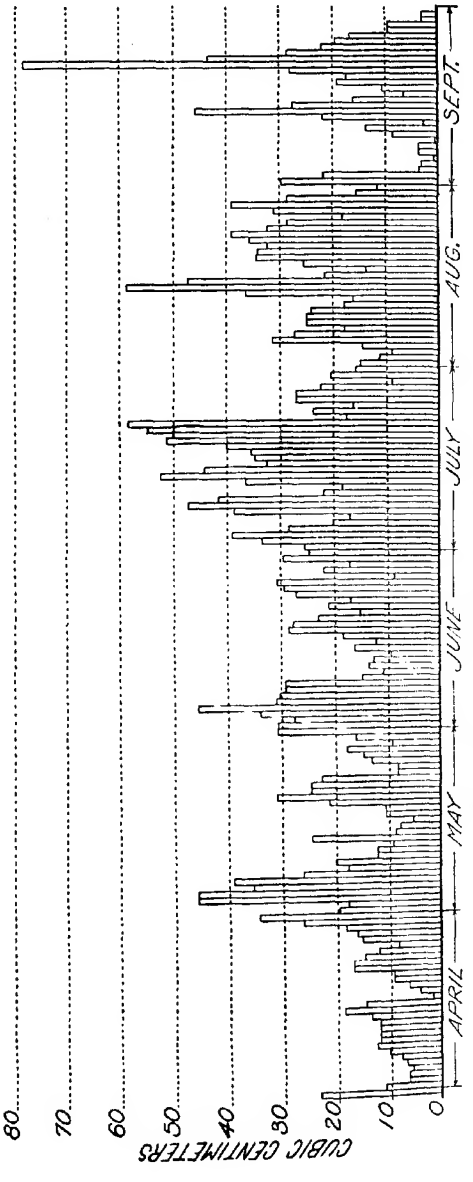

FIG. 3.—Daily records of evaporation, Corvallis, Oreg., summer of 1919.

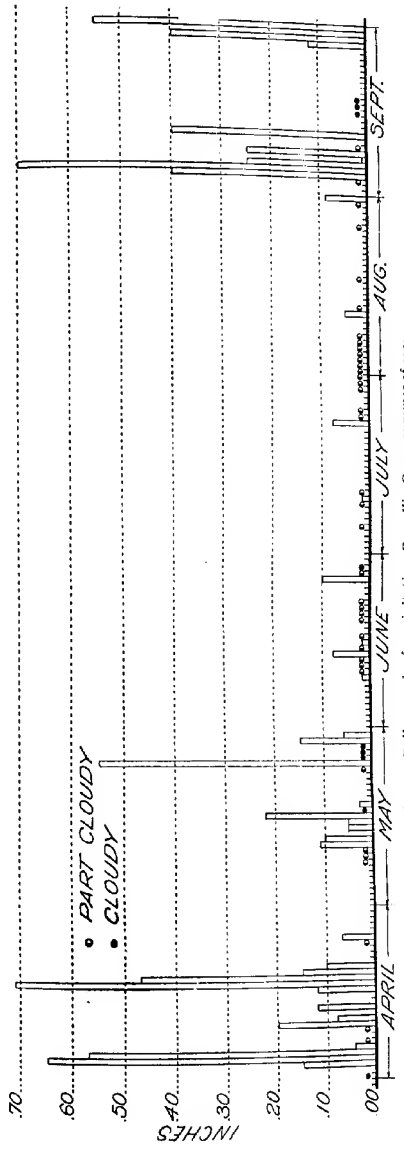

FIG. 4.—Daily records of precipitation, Corvallis, Oreg., summer of 1919.

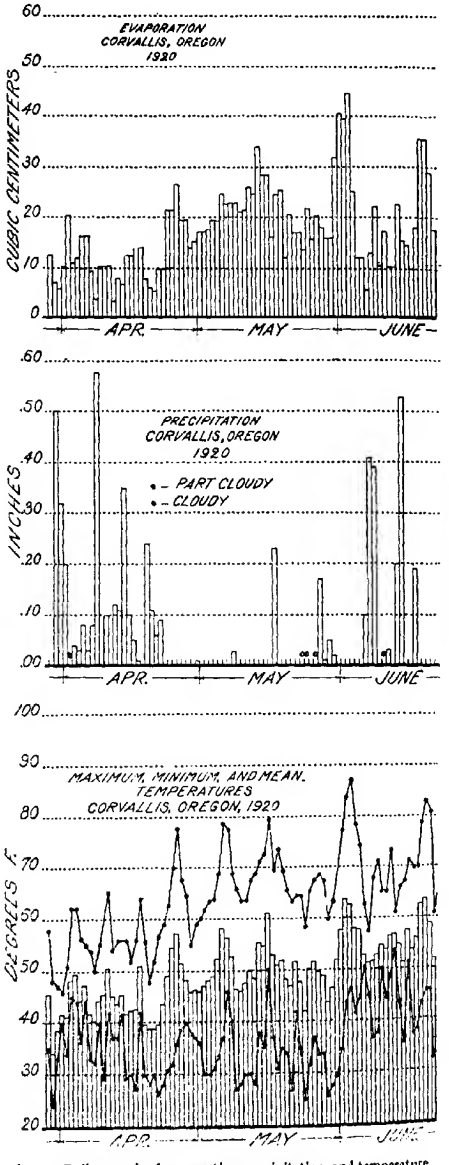

FIG. 5.—Daily records of evaporation, precipitation, and temperature. Corvallis, Oreg., summer of 1920.

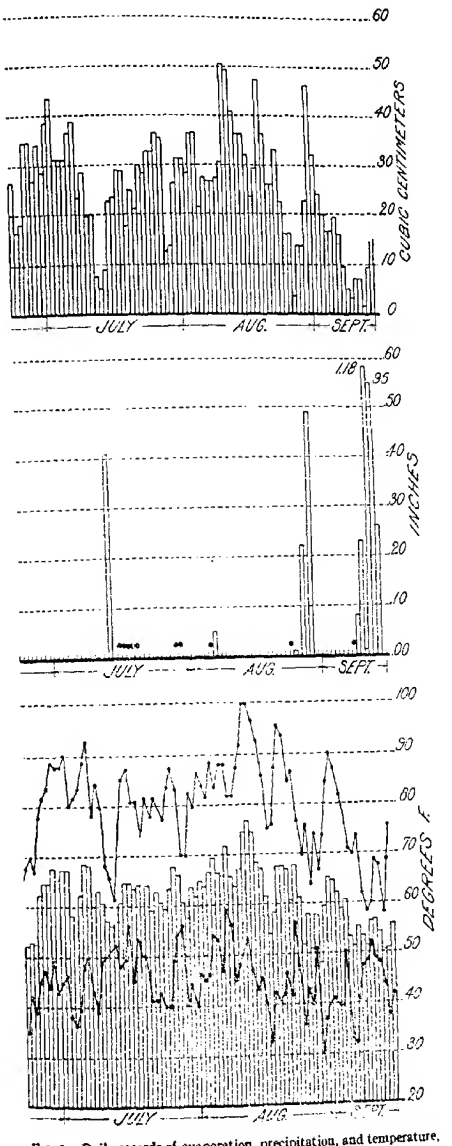

FIG. 6.—Daily records of evaporation, precipitation, and temperature, Corvallis, Oreg., summer of 1920.

During the summer of 1919 the highest daily evaporation of 78.6 cc occurred on September 21. This was probably due to continuous wind movement rather than to unusually high temperature or low humidity. The highest evaporation recorded during 1920 occurred on August 11, being 50.9 cc. As would be expected, there is a marked correlation between the amount of evaporation and precipitation and temperature, the highest evaporation occurring during periods of high temperature and little precipitation. Wind is also an important factor, and the character and duration as well as the actual amount of precipitation has a great influence upon evaporation. A long period of light rainfall retards evaporation more than a short period of heavy rainfall, although the actual amount of precipitation may be greater in the latter case.

A study of the data here presented shows that there is a general correlation between the rate of evaporation and the rate of development of *Aphis pomi*. On the whole, a high rate of evaporation was accompanied by a rapid development of the aphids, and a low rate of evaporation by a comparatively slow development of the insects. While this correlation seems to be true in a general way, there is considerable variation from the rule. The variation which may occur in the average daily rate of evaporation during any given length of developmental period is illustrated graphically in figure 7.

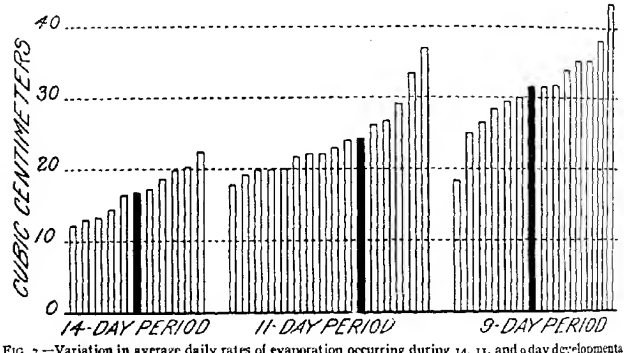

FIG. 7.—Variation in average daily rates of evaporation occurring during 14, 11, and 9 day developmental periods. White bars represent average daily evaporation, individual records. Black bars represent the means of all records of their respective periods.

These results show that under the conditions of this investigation, evaporation, as registered by the standard evaporimeter used, is not a satisfactory measure of aphis metabolism. This condition apparently results from the fact that the combination of factors, humidity, temperature, wind, etc., which influence evaporation, affect evaporation from the standard porous cup in a manner which is not closely comparable to their effect upon the metabolism of *Aphis pomi*.

As pointed out by Livingston,[6] the rates of evaporation from different types of evaporimeters under any given complex of atmospheric conditions are not comparable. It is, therefore, not surprising that evaporation from an instrument as used in these experiments would not give an accurate index of the effects of the atmospheric conditions upon aphis metabolism. It is possible that an evaporimeter more closely simulating the conditions of the aphid body might give a closer correlation between atmospheric evaporation and insect metabolism.

[6] LIVINGSTON, Burton Edward. OP. CIT.

TABLE III.—*Relation of evaporation to rate of development of Aphis pomi, 1919*

Aphid series No.	Date of birth.	Date first young produced.	Developmental period.	Total evaporation.	Average daily evaporation.
			Days.	*Cc.*	*Cc.*
1	Mar. 31	Apr. 29	29	342.5	11.8
2	Apr. 29	May 17	18	410.0	22.8
3	May 17	June 2	16	294.0	18.4
4	June 2	17	15	336.2	22.4
5	3	18	15	335.5	22.4
6	4	18	14	293.6	14.5
7	5	19	14	285.9	20.4
8	6	20	14	277.8	19.8
9	9	23	14	242.7	17.2
10	10	24	14	265.9	18.9
11	12	25	13	260.7	20.0
12	13	24	11	217.4	19.8
13	17	29	12	268.8	22.4
14	18	29	11	240.2	21.9
15	20	July 1	11	243.3	22.1
16	21	2	11	253.5	23.0
17	22	3	11	265.7	24.1
18	23	3	10	248.5	24.8
19	24	5	11	288.8	26.2
20	25	7	12	296.5	24.7
21	26	8	12	304.3	25.4
22	27	8	11	295.5	26.9
23	28	9	11	320.9	29.2
24	29	8	9	256.6	28.5
25	30	10	10	316.0	31.6
26	July 1	11	10	313.0	31.3
27	2	12	10	306.1	30.6
28	3	12	9	272.6	30.3
29	4	14	10	322.4	32.2
30	6	15	9	318.0	35.3
31	7	17	10	368.4	36.8
32	8	19	11	405.5	36.9
33	9	18	9	317.9	35.3
34	11	20	9	345.9	38.4
35	12	22	10	429.0	42.9
36	13	22	9	392.5	43.6
37	14	21	7	286.1	40.9
38	16	24	8	339.4	42.4
39	29	Aug. 9	11	196.9	17.9
40	30	10	11	222.1	20.2
41	31	11	11	245.0	22.3
42	Aug. 3	11	8	192.9	24.1
43	4	17	13	382.5	29.4
44	7	17	10	309.1	30.9
45	8	18	10	305.1	30.5
46	11	19	8	238.0	29.8
47	12	20	8	254.6	31.8
48	13	20	7	238.5	34.1
49	14	23	9	304.3	33.8
50	16	24	8	237.2	29.7
51	19	28	9	286.9	31.8
52	20	30	10	320.1	32.0
53	21	30	9	285.9	31.7
54	23	Sept. 2	10	274.0	27.4
55	24	5	12	263.7	21.9
56	25	7	13	235.8	18.1
57	26	7	12	207.9	17.3
58	27	9	13	193.2	14.8
59	28	12	15	187.2	12.5
60	29	13	15	170.1	11.3

TABLE III.—*Relation of evaporation to rate of development of Aphis pomi, 1919*—Con.

Aphid series No.	Date of birth.	Date first young produced.	Developmental period.	Total evaporation.	Average daily evaporation.
			Days.	*Cc.*	*Cc.*
61	Aug. 30	Sept. 22	24	392.5	16.4
62	31		14	170.8	12.2
63	Sept. 1		15	187.9	13.4
64	2		13	159.0	12.2
65	3		15	170.5	11.4
66	5		14	183.0	13.1
67	6		13	182.3	14.0
68	8		13	220.8	17.0
69	10		11	211.6	19.2
70	11		12	319.6	26.5
71	13		15	392.6	26.2
72	16		14	315.7	22.5

TABLE IV.—*Relation of evaporation to rate of development of Aphis pomi; summary of data for 1919 and 1920*

Length of developmental period.	Average total evaporation for period.	Average daily evaporation.	Number of records.
Days.	*Cc.*	*Cc.*	
36	453.9	12.6	1
29	342.5	11.8	1
24	392.5	16.4	1
22	406.6	18.5	1
19	412.6	21.7	1
18	408.0	22.7	2
16	294.0	18.4	1
15	265.3	17.7	6
14	236.5	16.9	10
13	256.9	19.7	10
12	265.8	22.1	8
11	266.2	24.2	15
10	305.2	30.5	14
9	284.2	31.6	14
8	252.4	31.5	5
7	262.3	37.5	2

TEMPERATURE STUDIES

The data obtained during 1919 showed that, while there is a general correlation between evaporation and the rate of metabolism of *Aphis pomi*, a measure of evaporation alone is not a satisfactory index to aphid development. During the summer of 1920 the investigation was continued and accurate records of temperature as well as evaporation were maintained.

The daily maximum, mean, and minimum temperatures for the summer of 1920 are given in Table II and are shown graphically in figures 5 and 6. It will be noted that there was considerable daily variation in temperature ranging from a minimum variation of 7° F. on April 1 to the maximum variation of 54° on August 14. In general, the greatest daily variation occurred during periods of high mean temperatures and was correlated with a high rate of evaporation. Periods of little daily variation in temperature were usually accompanied by low mean temperatures, by little evaporation, and frequently by precipitation.

[3] Table V shows the relation of temperature to the rate of development of *Aphis pomi*. The actual mean temperatures of the developmental periods of the several series were first plotted as shown by the circles on the graph, figure 8. It was found that these points lie approximately along

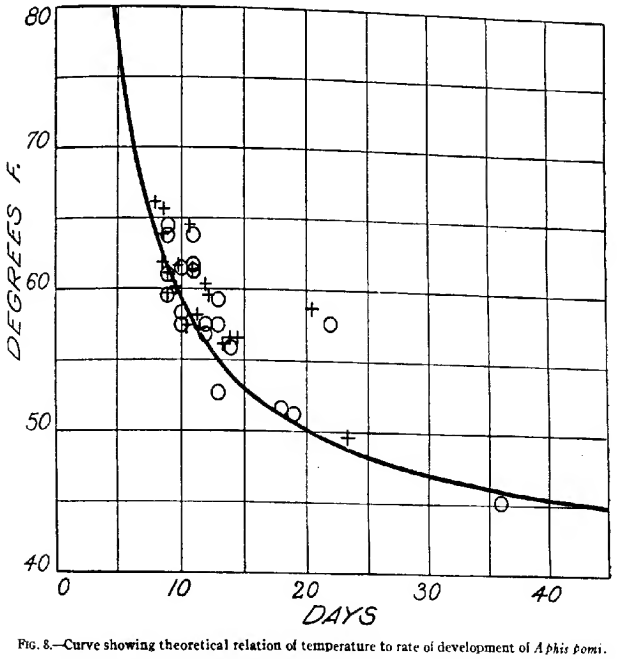

FIG. 8.—Curve showing theoretical relation of temperature to rate of development of *Aphis pomi*.

a hyperbolic curve having the formula $x=\frac{a}{y-b}$.[7] This formula may be expressed by the formula: Length of developmental period in days

$$=\frac{180}{\text{Temperature in degrees Fahrenheit}-41}.$$

If the curve thus plotted be extended it will be found that as the temperature is lowered the development of the aphids becomes less rapid, until at a temperature of 41° F. or less development ceases entirely. In other words, only temperatures above 41° are "effective"[8] in the development of *Aphis pomi*. By subtracting all temperatures of 41° or less and by computing the mean of the remaining temperature readings the mean effective temperatures (Table V) were obtained. By subtracting from the developmental period the time during which the temperature was 41° or less the duration of effective temperature was determined. These data were then plotted on the graph (fig. 8) as indicated by the crosses.

[7] The writer is indebted to Prof. E. B. Beaty, of the Department of Mathematics, Oregon Agricultural College, for the computation of the formula for this curve.

[8] SANDERSON, E. DWIGHT. THE RELATION OF TEMPERATURE TO THE GROWTH OF INSECTS. *In* Jour. Econ. Ent., v. 3, no. 2, p. 113-139, fig. 6-26. 1910. Authors cited, p. 138-139.

TABLE V.—*Relation of temperature and evaporation to rate of development of Aphis pomi, 1920*

Aphid series No.	Date of birth.	Date first young produced.	Developmental period.	Total evaporation.	Average daily evaporation.	Mean temperature.	Duration of effective temperature.	Mean effective temperature.
			Days.	*Cc.*	*Cc.*	°*F.*	*Days.*	°*F.*
1.....	Mar. 28	May 3	36	453.9	12.6	45.1	23.3	49.7
2.....	May 3	16	13	312.4	24.0	52.6	10.4	57.4
3.....	13	June 1	19	412.6	21.7	51.3	14.5	56.5
4.....	16	3	18	406.0	22.6	51.6	13.9	56.5
5.....	31	12	12	249.1	20.8	56.8	11.6	57.3
6.....	June 2	16	14	231.5	16.5	55.9	13.3	56.2
7.....	9	21	12	216.8	18.1	57.5	11.4	58.1
8.....	14	27	13	324.0	24.9	57.5	12.2	59.6
9.....	17	27	10	274.7	27.5	58.2	9.5	60.0
10.....	21	30	9	238.1	26.5	59.5	8.6	61.8
11.....	27	July 6	9	265.3	29.5	64.5	8.7	65.7
12.....	30	9	9	302.7	33.6	63.8	8.7	63.9
13.....	July 7	18	11	218.8	19.9	61.1	10.9	61.3
14.....	9	18	9	166.7	18.5	61.0	9.0	61.1
15.....	18	28	10	273.6	27.4	62.5	9.8	62.7
16.....	28	Aug. 6	9	226.1	25.1	64.5	8.0	66.1
17.....	Aug. 12	23	11	368.7	33.5	63.8	10.7	64.3
18.....	20	Sept. 2	13	298.6	22.9	59.3	12.0	60.2
19.....	20	11	22	406.6	18.5	57.6	20.5	58.6
20.....	23	2	10	212.9	21.3	57.5	9.0	59.8

In general, the records as shown on figure 8 do not coincide exactly with the theoretical curve of development. This is no doubt due largely to the fact that observations of the aphids were made only once daily, which would tend to cause a lagging in the recorded rate of development of the insects. Toward the end of the growing season the development of the aphids in some of the series was probably retarded to some extent by the lack of succulence of the plant tissues, in spite of the fact that the most succulent growing tips were selected for rearing the aphids. The extent to which development may be retarded by such a limiting factor is shown by series 19, which was reared upon mature foliage. For its development this series required a period of effective temperature of 20.5 days, although accompanied by a mean effective temperature (58.6°) high enough to permit development in half the time consumed. This effect of the growth of the plant upon the development of *Aphis pomi* was also noted by Baker and Turner,[9] who regard it as a food relationship. It is evident that the condition of the foliage of the food plant frequently constitutes a limiting factor of considerable importance to the activities of *Aphis pomi*.

CONCLUSIONS

Under normal outdoor conditions there is a general correlation between atmospheric evaporation and the rate of development of *Aphis pomi*.

Atmospheric evaporation, as measured by the standard evaporimeter used, does not serve as a satisfactory index to the rate of development of *Aphis pomi*.

[9] BAKER, A. C., and TURNER, W. F. MORPHOLOGY AND BIOLOGY OF THE GREEN APPLE APHIS. In Jour. Agr. Research, v. 5, no. 21, p. 983, pl. 75. 1916.

Temperature, during periods when no other factor limits the rate of development of the species, constitutes a more satisfactory index than does the rate of atmospheric evaporation.

The relation of temperature to the rate of development of *Aphis pomi* may be represented by a hyperbolic curve having the formula: length of developmental period in days $= \frac{180}{\text{Temperatures in degrees Fahrenheit} - 41}$.

Plant growth frequently constitutes a factor limiting the rate of development of *Aphis pomi* feeding on slowly growing foliage.

DOWNY MILDEW ON LETTUCE IN CALIFORNIA

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INTRODUCTION

Downy mildew caused by *Bremia lactucae* Regel was reported several decades ago by Arthur (*1*),[2] Burrill (*4*), Halsted (*6, p. 175–176*), and Farlow (*5, p. 313*), as occurring in this country on lettuce grown under glass. During a long period following these early reports, investigators appear not to have given any intensive attention to this disease outside of Europe, where Marchal (*7*) obtained partial control of it by the application of chemicals to the soil. Recently, downy mildew was reported as causing slight losses, usually in greenhouses, in most of the Northeastern States and in Ohio, Indiana, Iowa, and Texas. With the exception of these notes on the occurrence of the disease, referring to it entirely as a greenhouse problem, discussions of *B. lactucae* in literature have been meager, and no attention appears to have been given to it as a pathological problem of lettuce grown in the field on a commercial scale. In California, where extensive acreages are annually planted to lettuce, downy mildew has become an important factor both in production and transportation.

EARLY CLASSIFICATION OF THE FUNGUS

Bremia lactucae was first recorded as a parasite on lettuce and other compositae in Europe in 1843. Although the fungus retained its position among the Peronosporaceae, according to Saccardo (*8, p. 244*), it was discussed later by Berkeley (*3*), de Bary (*2, p. 108*), and others under the names of *Peronospora gangliformis* (Berk.) de Bary, *Botrytis ganglioniformis* Berk., *Peronospora ganglioniformis* Berk., *P. nivea*, *Botrytis lactucae*, *Botrytis geminata*, *Botrytis sonchicola* Schlecht., and *Actinobotrys tulasnei* Hoffm.

DISTRIBUTION OF THE DISEASE IN CALIFORNIA

The most important commercial lettuce-growing areas of California are located in the Imperial Valley and the Los Angeles, Sacramento, and Watsonville districts. During the season of 1919–20, there were approximately 19,000 acres of lettuce in these districts, and the major portion of the product of this acreage was destined for carlot shipments to markets in all parts of the country. The lettuce planted consists largely of the variety known as New York.[3] During the past few years about 85 per cent of the total annual acreage has been planted to

[1] Accepted for publication July 2, 1921.

[2] Reference is made by number (italic) to "Literature cited," 991.

[3] The variety New York is also known locally as Los Angeles and Los Angeles Market. In Eastern markets it is frequently erroneously called Iceberg. Other synonyms of this variety are Henderson's New York, Bonanza, Schwill's Bonanza, Queen, Faust's Queen, Sterling, Hastings's Drum Head, Wonderful, and Neapolitan.

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this variety, while the remaining 15 per cent consisted largely of the varieties known as Iceberg and Big Boston. Both New York and Iceberg are cabbage-heading varieties, the former wholly green and the latter greenish with a brownish tinge. Synonyms for Iceberg are Burpee's Iceberg, Curled India, and Weaver's Market Gardener's. Synonyms were taken from the work of W. W. Tracy, jr. (9).

With the concentration of the industry upon one variety to the extent of 85 per cent, an increasing amount of downy mildew has developed, particularly since the variety New York is highly susceptible to that disease. In the Imperial Valley the disease was found in a milder form than in other districts. In the Los Angeles district the fungus was found on lettuce during all months of the year but appeared to be most active from October to May. During this period, in many fields where the plants were approaching condition for harvest, 90 per cent of the crop was affected severely, that is to say the fungus was found on most of the exposed leaves regardless of age. In a survey of the whole district during the season of 1919–20 an estimate of 40 per cent severe infection was made. In the Watsonville and Sacramento districts the severity of the disease was similar to that in the Los Angeles district.

SYMPTOMS OF THE DISEASE

The first indications of infection appear as scattered light green to yellow areas on the upper surface of the leaf. Any exposed leaf may be attacked, although the oldest leaves frequently show the first signs of infection. Shortly after the appearance of these discolored areas, the fungus develops on the lower surface of the leaves as patches of downy white directly beneath the discolored areas. Conidial development is almost simultaneous with the appearance of the fungus on the lower surface. The size of the spots varies from ½ to ¾ inch in diameter, the surface development of the organism being limited by the extent of spread within the tissues of the host. Frequently spots coalesce and when of long standing take on a brown color, giving rise to the term "brown margin" recently employed by inspectors of the Bureau of Markets (Pl. 1).

DESTRUCTIVENESS OF THE DISEASE

The frequency and severity of infection of lettuce heads makes selection in the field and close trimming in packing for shipment impracticable. In packing, the outer leaves, usually three to four in number, are removed. This amount of trimming does not reduce appreciably the amount of infection, since not only do the outer leaves contain brown lesions or spots but many of the younger leaves are covered with later infections.

For immediate local consumption lettuce so affected as to have the margins of the outer leaves browned and white patches of fungus on other exposed parts is not greatly reduced in value, but when such lettuce is stored or shipped, rapid deterioration through decay is likely to occur. That a large portion of the crop is shipped out of the State is shown by the record of over 5,789 cars of lettuce shipped during the year from July, 1919, to July, 1920.

Bremia lactucae was found to remain vigorous and even to flourish on lettuce in cars under refrigeration on arrival at destination. Dr. G. K.

K. Link, in an unpublished report, stated that the fungus was abundant on lettuce shipped from California to Houston, Tex., New Orleans, La., and Chicago, Ill. On arrival at these points, the heads were badly decayed. That such decay occurs readily was established in the laboratory, where lettuce heads, some severely affected with lesions caused by *Bremia lactucae* and some normal, were placed under similar conditions and where the affected heads always decayed more rapidly than normal heads. A number of secondary organisms in the form of species of Macrosporium, Cladosporium, Botrytis, Fusarium, and Aspergillus were isolated from lesions caused by *Bremia lactucae*, and of these several are capable of causing decay.

CAUSAL FUNGUS

Bremia lactucae has long been known as one of the Peronosporaceae. En masse, the fungus when first appearing on the outer portion of the leaf is of a snowy white color. Microscopically, both mycelium and conidia are hyaline. In the host the mycelium grows between the cell walls, projecting modified club-shaped haustoria into the cells. Aerial portions of the fungus proceed generally from stomatal openings, at which point a single issuing hypha forms a bulbous swelling. From this swelling two or three conidiophores arise, with an average length of 190 microns from the base to the first branches. The conidiophores are nonseptate and profusely branched, both dichotomously and trichotomously. At the distal end of each branch a cuplike swelling projects four or five sterigmatic and radiating branchlets, each bearing a single conidium. The conidia are ovate, hyaline, papillate, and average 18.5 by 17.5 microns in size (Pl. 2).

Reproduction takes place through direct germination of conidia by means of a germ tube, by the production of zoospores, and by formation of oospores. Heretofore, the first and third methods of reproduction have been mentioned in literature, while the second, the production of zoospores, has not been recorded up to this time. Direct germination was readily obtained when freshly collected conidia were placed in a hanging drop culture for a period of 24 hours. While the formation of germ tubes by conidia under aquatic conditions was being studied free-swimming zoospores were frequently observed. Numerous and careful preparations of cultures through selection of individual conidia led the writer to conclude that under certain conditions conidia developed zoospores, while under others they germinated directly. It was found that conidia produced during the cool months, December to March, inclusive, formed zoospores more readily than those conidia collected during the warm season of the year. The most favorable conditions for the development of zoospores were found to be darkness and a temperature in the vicinity of 10° C. After the preparation had been subjected to these conditions for a period of 24 to 48 hours, an abundance of motile ciliated spores could be observed. These spores were hyaline, globular, ciliated, motile for several hours, and about 4.2 microns in diameter. The exact period of motility was not determined. After emergence of the zoospores, the epispore collapsed quickly. The number of zoospores formed in each conidium seemed to vary; however, it was greater than eight. The media employed in this study were physiological salt solution, tap water, 0.1 per cent dextrose solution, and 0.1 per cent bacto-peptone solution. Common tap water

appeared to be as efficient as any other medium for the inducement of zoospore formation, while in dextrose solution there was a greater tendency to direct germination of the conidia. After coming to rest, the zoospores germinated with regularity (Pl. 2).

The complete pathological significance of zoospore production must be determined through further investigation. It is very evident that environmental conditions play an important part in the determination between direct germination and zoospore formation. Although direct germination occurs in the absence of light and at 10° C., zoospore formation predominates under those conditions, and one is led to conclude that zoospores provide for the reproduction of the fungus at low temperatures.

SUSCEPTIBILITY OF LETTUCE VARIETIES TO THE ORGANISM

The disease was found on lettuce during all parts of the year, but the severest infections occurred during the winter months. It was thought that the control of soil moisture during irrigation might inhibit the development of the fungus. In order to accomplish such control, seed beds were constructed about 8 inches above the irrigation furrow, on the experiment field of the Office of Cotton, Truck, and Forage Crop Disease Investigations, located at Alhambra, Calif. Irrigation water was then allowed to rise in the furrow to a line 4 inches below the surface of the seed bed. This attempt to reduce soil surface moisture and subsequent condensation of moisture on the plant's leaf surfaces was futile in the winter months, because of rains and frequent fogs. During the rainless months a considerable amount of the fungus developed, but not to as great an extent as during the rainy season.

In carrying out varietal tests of lettuce, it was soon found that the variety New York was highly susceptible to mildew, while several other varieties showed evidence of resistance. During two consecutive years six separate plantings were made each year. In each test 200 plants of each variety were kept under observation. In each test the contrast in susceptibility between the varieties New York and Iceberg was markedly evident. Iceberg appeared to be highly resistant. The relative susceptibility of four varieties of lettuce in two tests during the season of 1919–20 is expressed in the following table.

Variety.	Number of plants.	Number of plants infected.	
		Test 1.	Test 2.
New York	200	196	170
Iceberg	200	1	0
Big Boston	200	10	6
Hanson	200	12	8

The contrast in susceptibility between New York and Iceberg (Pl. 3) is obviously in favor of the inferior variety. New York has supplanted Iceberg in recent years on account of the production of a firmer and larger head during the winter months, the main growing season. Iceberg excels during the summer months, when high temperatures retard

the development of the New York. The latter is so well established in the trade that an advocacy of substitution by Iceberg would be viewed askance by shippers at present. On account of an unfolding of its advantages in the summer months, when a small amount of Iceberg is shipped, the two varieties rarely meet on the market in competition. The variety known as Hanson, an intermediate variety between New York and Iceberg, shows considerable resistance to downy mildew. The solution of the problem rests in the selection of individuals among the resistant varieties, for firmness and size of head.

SUMMARY

Climatic conditions in California are favorable and conducive to the growth of *Bremia lactucae* on lettuce in the field. The abundance of the fungus has given rise to an important problem in transportation as well as in the field. Reports by inspectors of the Bureau of Markets point to frequent deterioration of lettuce in transit due to this fungus, which invades the plant in the field.

The solution of the field problem has been approached in a large measure by the determination of the existence of resistance in certain varieties of lettuce.

The additional method of reproduction found in *Bremia lactucae* on lettuce in California in the form of zoospore production, heretofore unrecorded, does not change the position of the fungus in the Peronosporaceae.

LITERATURE CITED

(1) ARTHUR, J. C.
1886. LETTUCE MILDEW. PERONOSPORA GANGLIFORMIS DEB. *In* N. Y. State Agr. Exp. Sta., 4th Ann. Rpt., 1885, p. 279–280, fig. 4.

(2) BARY, Anton de.
1863. RECHERCHES SUR LE DÉVELOPPEMENT DE QUELQUES CHAMPIGNONS PARASITES. *In* Ann. Sci. Nat. Bot., ser. 4, tome 20, p. 5–148, 13 pl. Bibliographical footnotes.

(3) BERKELEY, M. J.
1846. OBSERVATIONS, BOTANICAL AND PHYSIOLOGICAL ON THE POTATO MURRAIN. *In* Jour. Hort. Soc. London, v. 1, p. 9–34, 4 pl.

(4) BURRILL, T. J.
1876. UPON PARASITIC FUNGI. *In* Ill. Mus. Nat. Hist. Bul. 1, p. 52–59.

(5) FARLOW, W. G.
1883. ENUMERATION OF THE PERONOSPOREAE OF THE UNITED STATES. *In* Bot. Gaz., v. 8, p. 305–315.

(6) HALSTED, Byron D.
1882. FUNGI INJURIOUS TO VEGETATION WITH REMEDIES. *In* 15th Ann. Rpt. Conn. Bd. Agr., 1881–82, p. 157–191. Discussion, p. 177–191.

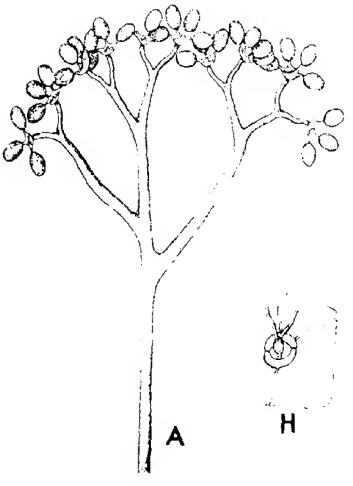
(7) MARCHAL, E.
1902. DE L'IMMUNISATION DE LA LAITUE CONTRE LE MEUNIER. *In* Compt. Rend. Acad. Sci. [Paris], tome 135, p. 1067–1068.

(8) SACCARDO, P. A.
1888. SYLLOGE FUNGORUM. v. 7. Patavii.

(9) TRACY, W. W., Jr.
1904. AMERICAN VARIETIES OF LETTUCE. U. S. Dept. Agr. Bur. Plant Indus. Bul. 69, 103 p., 27 pl.

PLATE 1

Single leaf of New York variety of lettuce showing brown or old lesions caused by *Bremia lactucae*. The light areas in the left of leaf are new infections.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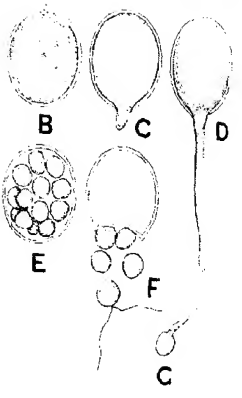
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PLATE 2

Bremia lactucae Regel: Various stages in the life history of the fungus.
A.—Condiophore bearing conidia and showing arrangement.
B.—Single conidium.
C.- Germination of conidium.
D.—Conidium with zoospores ready for emergence.
E.—Zoospore after emergence from conidium.
F.—Zoospore germinating.
G.—Stoma of lettuce leaf, showing origin of conidiophore.

PLATE 3

Two varieties of lettuce from test plot, showing difference in susceptibility to *Bremia lactucae*. New York on the left shows numerous brown lesions and high susceptibility. Iceberg on the right is entirely clean; shows high resistance.

U.S. Dept. of Agriculture, Research Service

DETERMINATION OF STARCH CONTENT IN THE PRESENCE OF INTERFERING POLYSACCHARIDS[1]

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INTRODUCTION

No method of analysis by which it is possible to determine accurately the quantity of starch present in materials containing plant mucilages, pectins, or similar interfering polysaccharids has yet come to the attention of the authors. Such a method, if reasonably practicable, should be of direct aid to feed-control officials confronted with the problem of detecting adulteration in linseed meal and cake. It is an open secret that from time to time unscrupulous millers or dealers handling linseed by-products (cake, meal, and flaxseed screenings) have resorted to the following practices: The so-called "fine screenings" from flaxseed are run in with clean seed on the way to the crushers, in sufficient quantity to bring the total content of "dockage" up to about 5 per cent; flax screenings are crushed and pressed for low-grade oil, and the resulting screenings cake is ground and mixed with ground linseed cake in varying proportions; chaff, fine screenings, etc., removed from flaxseed, are pulverized and used to adulterate linseed meal.

It is impossible to determine the quantity of the adulterant, or even to prove sophistication, unless it is excessive, by making the chemical analysis usually applied to feedingstuffs (*8*),[2] because of the variations in composition of pure flaxseeds from different sources and the diverse character of the "dockage" or impurities associated with the seed. The seed of the flax plant, however, contains no starch. Therefore any starch found in a linseed cake or meal is an impurity derived from foreign or nonflax tissues present in the product examined. A small quantity of such nonflax material, however, does not necessarily constitute an adulteration. The Association of Feed Control Officials of the United States holds that the maximum quantity of weed seeds and other foreign materials legitimately permissible in linseed cake or meal is 6 per cent,[3] equivalent to 4 per cent of foreign matter in the seed before crushing. From data collected by the Bureau of Chemistry (*8*), it follows that linseed cake or meal containing less than 38 per cent of crude protein, more than 11 per cent of crude fiber, or more than 2 per cent of starch, when calculated to a moisture-free and ether-extract-free basis, is open to the suspicion of having been adulterated. As the starch content of the nonflax material normally associated with flaxseed would rarely, if ever, be greater than 50 per cent,[4] any linseed cake or meal containing more than 3 per cent of starch should be considered to be adulterated.

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[1] Accepted for publication Feb. 20, 1923.

[2] Reference is made by number (italic) to "Literature Cited," p. 1000.

[3] In the definitions of the association there is the further provision that no portion of the stated 6 per cent of weed seeds and other foreign materials shall be deliberately added.

[4] This opinion is based on the nature of the flaxseed "dockage" examined for a large number of samples of country, terminal, and mill seed (*8*).

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An accurate method for the determination of starch in linseed by-products could be used also to determine starch in apple pomace and other pectin-bearing materials. It would doubtless be of value also to analysts engaged in researches in dietetics, in determining the starch content of diabetic foods containing troublesome plant slimes and mucilages, for example.

There are two serious difficulties in the determination of starch in material like linseed meal: (a) It is nearly impossible to effect the preliminary elimination of sugars [5] and other interfering carbohydrates by extraction with cold water or 10 per cent alcohol, as required in the official methods (*1, p. 95–96*), because the mucilaginous substances present in linseed meal form an almost impervious layer on the filter, greatly retarding percolation, if not preventing it. (b) Linseed mucilage, like other vegetable mucilages and pectins, is a polysaccharid, and must be excluded from the material subjected to acid hydrolysis. Otherwise it will yield reducing sugars, thereby increasing the apparent starch content.

The official direct acid hydrolysis method is therefore barred from use at the outset. The official malt-diastase method, based on selective carbohydrate hydrolysis,[6] can not be employed because of the first difficulty mentioned. Even if the problem of washing out interfering sugars be solved, after the malt digestion the mucilage has lost none of its capacity for obstructing filtration and it is practically impossible to separate the starch conversion products from the rest of the material in aqueous solution.

There are, of course, colorimetric methods, in which advantage is taken of the blue color of the compounds of starch with iodin. One of the most promising modifications of this type, that of Cassal (*2*), was employed in estimating the starch content of apple pomace. Because of differences in the quality of color obtained and consequent difficulty in establishing an accurate comparison between the depth of this color and that of the starch-iodin standard, however, it was thought that this type of method could not meet the requirements in accuracy and dependability.

EXPERIMENTAL.

PRELIMINARY METHOD

Because of its coagulating effect on colloidal polysaccharids, such as pectins, mucilages, etc., strong alcohol can be used to eliminate these substances by precipitation, after conversion of the starch by selective enzyms. For this to be of value, however, the starch conversion products must remain in solution in the same strong alcohol.

The work of Davis and Daish (*3*) indicated that by employing taka-diastase as the amylolytic enzym this condition could be fulfilled. These investigators reported that by digesting with taka-diastase at 38°C. for a sufficient length of time, starch is quantitatively converted into maltose and dextrose, and into these sugars only. Neville (*5*) has shown that this enzym has no effect on linseed mucilage, and Schneider (*6*) reported that it does not hydrolyze apple pectin.

[5] Linseed meal normally contains from 3 to 4 per cent of nonreducing sugars, calculated as sucrose. A trace of reducing sugars is usually present. Similar results have been reported by Van Kampen(*7*).

[6] The mucilage of linseed meal is not hydrolyzed by the diastase of barley malt, according to Neville (*5*) nor is apple marc and its pectin, according to Schneider (*6*).

Accordingly, the starch content of several linseed meals, the approximate degree of purity of which had been ascertained,[7] (*8*) was determined by a method of which the following are the salient points:

After extracting with ether, the charge was leached with 70 per cent alcohol [8] to remove part at least of the sugars and other interfering substances. To correct further for any effect that might be exerted by interfering substances not extracted by the 70 per cent alcohol, a control determination was conducted, in which the starch hydrolysis was omitted and in which only the effect of the soluble carbohydrates was measured.

Hydrolysis of the starch was effected by digestion with taka-diastase, following the method of Davis and Daish (*3*).

Mucilage and other interfering polysaccharide were coagulated by 75 per cent alcohol and separated from the soluble starch conversion products, presumably maltose and dextrose, by filtration. After eliminating alcohol from the filtrate by evaporating over steam, the starch conversion products were hydrolyzed by acid and the dextrose was determined. The results obtained were corrected by deducting first the dextrose in the taka-diastase blank, and, second, the dextrose representing the control determination in which the starch was not hydrolyzed.

RESULTS OBTAINED WITH PRELIMINARY METHOD

The results obtained by this method on the linseed cakes and meals examined and the proximate analyses of these products are given in Table I.

TABLE I.—*Starch in linseed by-products of known composition* [a]

Material analyzed.	Nonflax matter.	Composition on original basis.						Composition on moisture-free and ether-extract-free basis.				
		Moisture.	Starch.	Ether extract.	Crude protein.	Crude fiber.	Ash.	Starch.	Crude protein.	Crude fiber.	Ash.	Starch content of nonflax matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Adulterated linseed meal (Sample 26691)	[b]28.0	10.0	7.2	6.8	30.5	10.0	5.8	8.7	36.6	12.0	7.0	25.7
Linseed cake containing excessive foreign matter (traced) (Sample 27243)	8.6	9.6	1.4	5.9	34.8	8.1	5.6	1.7	41.1	9.6	6.7	16.2
Linseed cake (traced) (Sample 27247)	3.8	10.2	1.4	6.8	34.8	8.1	5.3	1.7	41.9	9.7	6.4	36.8
Linseed cake (traced) (Sample 27262)	3.3	10.5	[c]1.0	6.7	35.8	7.8	5.1	1.3	43.2	9.4	6.1	[c]40.9
Adulterated linseed meal (Sample 27274)	[b]14.0	9.7	1.4	7.2	33.8	8.6	5.6	1.7	40.6	10.4	6.8	10.0
Flax screenings cake (traced) (Sample 27275)	89.8	9.4	16.3	8.4	17.9	16.0	8.3	19.8	21.8	19.5	10.1	18.2
Nonflax matter from flax screenings (composition calculated)	100.0	.....	.....	.....	.....	.....	.....	22.0	19.1	23.5	9.4	.....
Linseed cake (traced) (Sample 27276)	5.6	10.5	1.8	5.0	34.9	8.1	6.5	2.1	41.4	9.5	7.7	32.1

[7] These meals were prepared from traced linseed cakes. The investigator took samples from the seed entering the rolls, traced the seed through the crushing, cooking, and pressing, and took a representative section of the resulting cake. The percentage of nonflax material in the seed was ascertained without difficulty. As practically all of the expressed oil comes from the flaxseed and for practical purposes constitutes one-third of the weight of the seed, it follows that the percentage of foreign matter in the cake or meal is 1½ times that in the seed crushed.

[8] It was subsequently shown that 35 per cent alcohol percolates through linseed meal with almost equal facility and is, of course, a better solvent for interfering carbohydrates (p. 998).

[a] The starch was determined by the taka-diastase method, corrected by a "control" determination.

[b] The content of nonflax material in this sample was calculated from data obtained through inspection of the mill.

[c] From subsequent work, the true starch content is believed to be 1.34 per cent (1.62 per cent on the dry, fat-free basis).

This method was tedious and open to the objection that nothing definite was known as to the fate of the interfering carbohydrates, other than the mucilage, during the taka-diastase digestion. Furthermore, Horton (*4*) questioned the validity of the conclusion of Davis and Daish, that starch was quantitatively converted by taka-diastase into maltose and dextrose.

REVISED METHOD

The apparent solubility in rather strong alcohol of the conversion products obtained through a properly conducted malt-diastase digestion of starch was considered.[9] Experiments were undertaken to test the feasibility of using strong alcohol as the medium for separating such starch conversion products from mucilage or other interfering polysaccharids. Neither the dextrine nor any other conversion product obtained by digesting starch with an infusion of barley malt (under conditions fully described on p. 1003–1004) was thrown out of solution[10] by alcohol of 60 per cent strength. Starch determinations made on 0.8 and 1.2 gm. charges of prepared starch, in which the conversion products were subjected to the action of 60 per cent alcohol, yielded results accounting for 100 per cent of the starch known to be present. On the other hand, alcohol of this strength served perfectly to coagulate and precipitate linseed mucilage and apple pectin. It was shown also that 35 per cent alcohol served well in the preliminary extraction of sugars and other carbohydrates that affect the results in a determination of starch.

A new method of analysis, consisting of the following steps, was devised: (a) Preliminary extraction with 35 per cent alcohol;[11] (b) conversion of the starch by an infusion of barley malt; (c) separation of mucilage or other interfering polysaccharid by its coagulation and precipitation in 60 per cent alcohol; (d) elimination of alcohol from the filtrate by evaporation and acid hydrolysis of the starch conversion products to dextrose; (e) defecation of the acid dextrose solution by phosphotungstic acid; and (f) determination of the dextrose by copper reduction.

RESULTS OBTAINED WITH REVISED METHOD

In order to test the accuracy of the method, determinations were made on charges containing known quantities of added starch. The starch used for this purpose was prepared by washing a good grade of cornstarch with water until the extract gave no blue color with iodin, washing with 95 per cent alcohol and then with ether, and finally drying in a vacuum oven at 65° to 70° C.

Analysis of this prepared starch gave the following results: Starch by the official acid hydrolysis method,[12] average of 4 determinations, 87.62 per cent; starch by the malt-diastase method, with the 60 per cent alcohol purification, average of 2 determinations, 87.19 per cent; ash, 0.10 per cent; nitrogen by a micro-kjeldahl determination, 0.077 per

[9] H. C. Gore, of the Bureau of Chemistry, showed that a heavy malt sirup formed a clear solution in alcohol of a concentration of more than 60 per cent.

[10] The highest concentration of starch conversion products tested was that corresponding to 1.5 gm. of original starch to 500 cc. of the 60 per cent alcohol. No turbidity developed overnight. In 80 per cent alcohol some turbidity was noticeable.

[11] Twenty-five per cent alcohol, being a better solvent, serves best with materials that are not impervious to it.

[12] This check determination was made by J. I. Palmore, of the Food Control Laboratory, Bureau of Chemistry.

cent. A combustion determination[13] of carbon and hydrogen gave the following results: Carbon, 40.67 per cent, and hydrogen, 6.68 per cent, indicating a hexosan content of 91.53[14] per cent and a water content (uncombined) of 8.79 per cent.

The foregoing determinations were made on the starch near the close of the experimental work, several months after the samples had been prepared. The material was quite hygroscopic, and the percentage of starch determined by modifications of the official malt-diastase method was higher at the time of preparing the starch than four and five months later. The percentage of starch ranged from 89.65 to 87.19, owing, it is believed, to the absorption of moisture from the air. The values accepted as representing the true starch content of this standard sample are 88.9 per cent for the earlier experiments and 87.5 per cent for the later work. Throughout this study, the factor 0.90 was used in calculating starch from dextrose. The factor 0.93 probably more nearly represents the actual yield (*1, p. 95*). Had this factor been used, the accepted values would have been 91.9 per cent for the earlier and 90.4 per cent starch for the later work. The validity of the figures showing the value of the methods of analysis is not affected by the factor used.

Working with dried apple by-products, with and without added starch, the new method was compared with the Cassal colorimetric method and the official malt-diastase method. The results obtained were not entirely satisfactory. While the official method yielded results that were too high, owing undoubtedly to the inclusion of some pectin, the alcohol precipitation method failed to fully account for all the starch present. The results obtained on a sample of linseed meal containing known quantities of starch also were unsatisfactory in this first test with the method.

CORRECTION OF REVISED METHOD

It was thought that the failure to account for all starch known to be present might be due to: (a) Formation of mucilaginous lumps in the material, during gelatinization, which subsequently served to shield particles of starch from the dissolving action of the malt extract; (b) failure to thoroughly break up the ropy coagulum formed in the 60 per cent alcohol, with consequent occlusion of some of the more concentrated portions of the solution; (c) adsorption of maltose and dextrine by the coagulated colloids.

Accordingly, the method of analysis was reviewed to correct any errors in technic. The details and precautions to be observed are fully set forth in the final statement of the method of analysis advocated (p. 1002–1005).

If adsorption of the starch conversion products were primarily responsible for the low results, it seemed reasonable to expect that this error could be obviated by double precipitation with the 60 per cent alcohol.

TESTING FOR ADSORPTION BY DOUBLE PRECIPITATION

After the first precipitation in 60 per cent alcohol, the 500 cc. of liquid was thoroughly mixed with the coagulum, by pouring the mixture

[13] The determinations of nitrogen, carbon, and hydrogen were conducted by J. F. Ellis, of the Nitrogen Section, Bureau of Chemistry.

[14] A small quantity of cell wall tissue (cellulose) in the sample counts as starch in a combustion determination.

back and forth from one container to another, and filtered through dry paper, care being taken to avoid the loss of any of the solution or material.[15] The filter was allowed to drain until there was no danger of loss of filtrate on removing the paper and its contents from the funnel. The total volume of filtrate that had drained through was ascertained. The aliquot represented by it[16] was designated F and the whole solution, Solution 1. Using about 150 cc. of hot water, the filter paper and coagulum contained in it were returned to the 500 cc. volumetric flask, care being taken to rinse back all material adhering to the containers previously used in the mixing operation. (This serves to redissolve the mucilage, and the solution also contains that portion of Solution 1 which did not drain through the filter.) The aqueous mixture in the 500 cc. flask was shaken hard and thoroughly and, after cooling, the colloids were reprecipitated with 316 cc. of 95 per cent alcohol, the precaution of adding the alcohol in small portions and mixing to keep the coagulated material broken up being taken.

The total volume of liquid was completed to 500 cc. with water, mixed as before, by pouring it back and forth, and filtered through dry paper. This filtrate is called Solution 2. Aliquots of 200 cc. of Solution 1 and Solution 2 were evaporated in separate beakers, over steam, and, after the usual acid hydrolysis and purification, the dextrose in each aliquot was determined.

The additional determination of dextrose can not be avoided when double precipitation is employed. Hypothetically, the charge of starch rendered soluble by the diastase digestion, after the precipitation of colloids by alcohol, may be considered as existing in two forms: Unadsorbed portion (S), freely in solution in the 60 per cent alcohol; and a portion (A) supposedly adsorbed by the coagulum.

As S is entirely in solution, its quantity is readily obtainable from the quantity of dextrose found in the aliquot of Solution 1. The estimation of A, however, is not so simple. In the second alcohol extract (Solution 2) there is presumably not only all of A[17], but also $\frac{500-F}{500}$ of S. (The quantity $\frac{500-F}{500}$ represents the aliquot of Solution 1 that adhered to the filter and coagulum.) Thus the dextrose determined on the 200 cc. aliquot of Solution 2 is represented by $\frac{200}{500}(A+\frac{500-F}{500}\cdot S)$ and the dextrose determined on the 200 cc. aliquot of Solution 1 is represented by $\frac{200}{500}\cdot S$. In the two equations indicated, F is known, and S and A are readily obtainable. The total dextrose representing the starch in the original charge should equal $S+A$. This value, of course, must be corrected for the dextrose determined in the malt blank. This correction properly is made by calculating back to the quantity of dextrose in the malt infusion added to the mash, and subtracting this directly from $S+A$. The remainder, multiplied by 0.9, gives the starch content.

[15] A correction was obtained for dextrose due to the malt infusion and filter paper, by proceeding with the malt blank determination in exactly the same way.

[16] The aliquot may be accurately and conveniently determined by weighing the original 500 cc. of solution (by deducting the weight of solid material from the total), and also the filtrate, on a balance sensitive to 1 gm.

[17] Theoretically this would not be strictly true, owing to the proportional distribution of solute maintained between solution and adsorbent. The quantity of starch conversion products so withheld from solution, however, would be negligible, because of the dilution.

c RESULTS OBTAINED WITH CORRECTED REVISED METHOD

Starch determinations by the new method, with the added feature of double alcohol precipitation, were made on a sample of linseed meal of known degree of purity and on mixtures of this linseed meal and known quantitites of starch. This linseed meal (Sample 27262) was a ground traced cake, and, as calculated from the foreign matter in the seed before crushing, contained 3.3 per cent of nonflax material. Analysis showed it to have the following percentage composition: Moisture, 10.5; ether extract, 6.7; crude fiber, 7.8; crude protein, 35.8; ash, 5.1.

The results obtained by a single 60 per cent alcohol defecation (represented by *S*), as well as by the double precipitation on the same charges, are interpreted in Table II.

TABLE II.—*Comparison of the single and double alcohol precipitation modifications of the malt-diastase method for starch in linseed meal*

Material analyzed.	Weight of linseed meal.	Weight of prepared starch added.	Total starch present (pure starch).	Total dextrose after 1 alcohol precipitation from Solution 1 (*S*).	"Adsorbed" dextrose from Solution 2, after subtracting $\left(\frac{500-F}{500}\cdot S\right)$, (*A*).	Total dextrose after 2 alcohol precipitations (*S*+*A*).	Starch by single alcohol precipitation method.				Starch by double alcohol precipitation method.			
							Weight of starch after correcting for malt control; derived from *S*.	Total.	Average.	Divided by total starch present.	Weight of starch found after correcting for malt control; derived from *S*+*A*.	Total.	Average.	Divided by total starch present.
Control (dextrose correction on malt infusion, etc.)	*Gm.*	*Gm.*	*P.ct.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*P.ct.*	*P.ct.*	*P.ct.*	*Gm.*	*P.ct.*	*P.ct.*	*P.ct.*
	....	....	.....	0.35625	0.02875	0.3850	.....	.....	.....	.....	.....	.....	.....	.....
	....	....	.....	.35937	.04023	.3996	.....	.....	.....	.....	.....	.....	.....	.....
Prepared starch (sample 40125)	.....	1.5	87.5	1.82344	.01003	1.8335	1.3190	87.94	87.19	99.6	1.2971	86.47	86.65	99.0
	....	....	.....	1.79844	.04101	1.8394	1.2965	86.44	.....	.....	1.3024	86.83	.....	.....
Linseed meal (sample 27262)	4.0	.....	1.34	.42031	.03033	.4506	.0563	1.41	1.34	100.0	.0525	1.31	1.39	97.0
	....	....	.....	.41406	.03553	.4496	.0507	1.27	.....	.....	.0510	1.29	.....	.....
Linseed meal and starch	3.8	0.2	5.65	.60312	.03056	.6337	.2208	5.52	5.49	97.2	.2173	5.43	5.27	93.3
	....	....	.....	.60000	.01883	.6188	.2180	5.45	.....	.....	.2039	5.10	.....	.....
Do	3.5	.5	12.11	.80531	.00880	.9041	.4837	12.09	11.87	98.0	.4600	11.52	11.35	93.7
	....	....	.....	.87500	.01423	.8892	.4635	11.04	.....	.....	.4472	11.18	.....	.....
Do	3.0	1.0	28.88	1.37344	.00797	1.3814	.9140	22.85	22.85	99.9	.8902	22.25	22.23	97.2
	....	...	.....	1.37344	.00600	1.3794	.9140	22.85	.....	.....	.8884	22.21	.....	.....

The second alcohol precipitation was not only unnecessary, but it became a source of error because of the increase in the value of the malt control. The dextrose determined on Solution 2 (*A*) does not represent adsorbed material. At least if there was any adsorption of starch conversion products, it was so slight as to be practically negligible.

Other conditions being constant, the weight of the solute [18] adsorbed should be proportional to the weight [19] of the adsorbent (in this case the coagulum). The quantity of coagulum being constant, the weight of solute adsorbed should increase with the concentration of the solute.

[18] By solute in this case is meant starch conversion products (maltose and dextrine).
[19] The adsorption is proportional to the active surface area of the adsorbent. This is assumed to be proportional to the weight.

In Table II, *A* is greatest for the malt controls, in which the concentration of solute was lowest and the quantity of coagulum was almost negligible.[20] Taking the other extreme (the mixture containing the largest quantity of added starch), the values for *A* are the smallest reported, while the concentration of solute was the second highest and the quantity of coagulum was relatively large.

While the indications are that there is little adsorption, if any, an attempt to explain from the data at hand the high relative values for *A*, particularly for the malt controls, must consist largely of theorizing. The quantities of cuprous oxid actually obtained (from an aliquot of Solution 2), on which the values for *A* are based, however, were small, ranging from 8.8 to 23.6 mgm. The application of any substantial correction for the effect on the copper reduction of the reagents used in defecation [21] to these results would greatly reduce the values for *A*, and the effect would be emphasized in the case of the malt controls, for which the yield of cuprous oxid from Solution 2 was smallest.

The results obtained by carefully following this method, using a single precipitation with 60 per cent alcohol, furnish sufficient evidence of its fundamental soundness, and the investigators recommend it for the determination of starch in materials which, like linseed meal and apple pomace, contain interfering polysaccharids. In using the method, however, the analyst must give painstaking attention to details, particularly to those operations dealing with the colloidal substances, such as the gelatinizing to a smooth paste, the thorough breaking up of coagula, and the subsequent mixing. It is also highly important to control carefully the conditions that prevail during the dissolving and conversion of the starch. Work conducted in the Bureau of Chemistry has shown that the starch is best brought into solution by starting the first digestion with malt infusion at a temperature well below 55° C., then slowly raising it to 70°, holding it there for the specified time, and continuing to increase the temperature to 80°. While the saccharifying enzyms (the maltase) are believed to be destroyed by temperatures of 70° and higher, other starch liquefying enzyms present in the malt infusion are more active at the higher temperatures, and complete solution of the starch is attained. The second saccharifying digestion is conducted at 55°.

Because of the difficulties mentioned, the method of analysis is discussed in greater detail than would ordinarily be necessary.

METHOD RECOMMENDED

PREPARATION OF MALT EXTRACT

Use clean, new barley malt of known efficacy and grind it only as needed. Grind the malt well, but not so fine that filtration will be greatly retarded. Prepare an infusion of the freshly ground malt, just before it is to be used. For every 80 cc. of the malt extract required digest 5 gm. of the ground malt with 100 cc. of distilled water, at room temperature, for 2 hours, or for 1 hour if the mixture can be stirred by

[20] The nature of the small quantity of coagulum from the malt controls differed from that obtained from linseed meal. This might have significance had there been sufficient adsorption to be of importance.

[21] There is some cause for believing that the use of phosphotungstic acid slightly increases the reduction of copper in Fehling's solution.

an electric mixer for periods of 5 minutes three or four times. Filter to obtain a clear extract. (It may be necessary to return the first portions of the filtrate to the filter.) Mix the infusion well.

PREPARATION OF CHARGE

Weigh out a definite charge of from 2 to 6 gm.[22] of the finely pulverized and well-mixed sample,[23] using the smaller charges in the case of materials containing much gel-forming substance. (The weight of starch in the charge must not exceed 1.5 gm.) Transfer to a dry filter paper held in place[24] in a glass funnel of the usual type. It is not necessary to use a hardened filter; any tight, high-grade paper, 12½ or 15 cm. in diameter, will be satisfactory.

EXTRACTION OF CHARGE

Extract the charge with 5 successive portions of ethyl ether, taking for each portion more than enough to cover the charge. Use a cover glass to retard evaporation. After completing the extraction, allow the ether to evaporate and extract the charge with weak alcohol. The concentration of the alcohol may be varied somewhat to suit the material under examination. For linseed meal 35 per cent alcohol (by volume) must be used, while for dried apple pomace 25 per cent alcohol is best. Use 300 cc. of the alcohol to obtain the required thoroughness of extraction. Follow this with several filterfuls of 95 per cent alcohol, and finish the leaching operations with a second ether extraction. (It is convenient to have the charge stand overnight at this point to allow the ether and alcohol to evaporate, as alcohol must be eliminated before starting the digestion with malt.)

Start the preparation of the malt infusion.

A correction for the dextrose in the malt extract is obtained by conducting a control determination, preferably in duplicate. Starting with a piece of the filter paper extracted with alcohol, distilled water is added, and the control is carried along side by side with the actual starch determination, being subjected to the gelatinization temperature, receiving the same quantities of malt extract, and being treated similarly in every respect.

GELATINIZATION

To return to the primary determination, transfer the paper and charge (free from more than traces of alcohol) to a 300 cc. Erlenmeyer flask, and mix well with from 20 to 30 cc. of distilled water, macerating paper and material to give a perfectly smooth paste. Add 100 to 125 cc. of boiling water. Mix quickly, but thoroughly, and with constant stirring. Then heat the contents of the flask until it boils freely. In the case of mucilaginous materials like linseed meal it is necessary to transfer the flask to a boiling water bath to complete the gelatinization. Gelatinize thoroughly, without scorching or adhesion of the material to the bottom of the flask. The mixture should be smooth and free from lumps.

[22] Charges of 4 gm. for linseed meal, or 3 gm. for dried apple pomace, have been found to be satisfactory.
[23] The entire sample should be ground to pass freely through a sieve of not less than 40 mesh to the inch. It is preferable to have the material sufficiently fine to freely pass a 60-mesh sieve.
[24] An ordinary paper clip serves well to clamp the paper in place.

MALT-DIASTASE DIGESTION

Cool to 50°C. or lower, add 20 cc. of the malt infusion, to controls as well as to charges, and place the flasks in a temperature-controlled water bath. Keeping the mash thoroughly mixed, gradually raise the temperature to 70°, taking from 20 to 30 minutes to accomplish this. Maintain at 70° for 30 minutes, stirring the mixture from time to time. Then increase the temperature to 80° and hold it there for 10 minutes. Finally heat to the boiling point. Keep the mixtures well stirred, as this amounts to a second gelatinization.

Cool the contents of the flasks and the water bath to 55° C. Add 20 cc. of the malt extract, mix well, and hold at 55° for 1 hour, stirring about once every 10 minutes. At the termination of the digestion rapidly increase the temperature to above 80°.

DEFECATION WITH 60 PER CENT ALCOHOL

The total volume of the hot mash should not exceed 200 cc. Transfer each mash to a 500 cc. volumetric flask. A little hot water may be used for rinsing, provided the total volume of the mixture does not exceed 200 cc. Reserve the flask for subsequent rinsing. Measure out 316 cc. of 95 per cent alcohol. Add a portion, a little at a time, to the contents of the flask, with thorough shaking between additions. As soon as enough alcohol has been added to coagulate the colloidal matter, allow the coagulum to settle somewhat, and pour a little of the supernatant liquid back into the Erlenmeyer flask used in the digestion, thoroughly rinsing the contents into the volumetric flask. Complete the addition of the 316 cc. of strong alcohol, with constant mixing, avoiding any loss of material, and, after cooling to room temperature, adjust the volume with water so that the quantity of liquid is 500 cc. (Allowance is made for the volume occupied by the charge by adding 3 cc. of water for every 4 gm. of charge present, after bringing the contents of the flask up to the 500 cc. mark.)

The starch conversion products from the original charge should be contained in the 500 cc. of 60 per cent alcohol. The determination may be interrupted at this stage for several days, if need be, but it would be necessary to readjust the volume of solution if there were a change in temperature.

Mix thoroughly, breaking up any ropy coagulum as much as possible, by pouring back and forth from one large breaker to another. Filter through dry paper. Test the solid residue for starch, either microscopically or by the iodin color test, after elimination of alcohol and gelatinization with water. If more than the merest trace of starch is found, reject the entire determination. Evaporate exactly 200 cc. of the filtrate on a steam bath to a volume of from 15 to 20 cc., or until practically all alcohol has been expelled. Do not allow the evaporation to proceed to dryness.

ACID HYDROLYSIS

Transfer the aqueous residue of starch conversion products to a 200 cc. volumetric flask with hot water, using a rubber policeman to recover all of the dextrine. Allow to cool somewhat, and complete the volume to 200 cc. Transfer the contents to a suitable digestion flask, add 20 cc. of hydrochloric acid (sp. gr. 1.125), and connect the flask with a reflux condenser. Heat in a boiling water bath for 2½ hours.

PURIFICATION OF DEXTROSE SOLUTION AND DETERMINATION OF DEXTROSE BY COPPER REDUCTION

Cool and, in the case of linseed meal or other material yielding solutions which at this stage need further purification, add not more than 1 cc. of a 10 per cent solution of phosphotungstic acid in 1 per cent hydrochloric acid. Mix and allow to stand for 15 minutes at least. Increase the volume with water to 250 cc. in a volumetric flask, mix well, and filter through dry paper. Partially neutralize 200 cc. of the filtrate while stirring by adding 10 cc. of a heavy solution of caustic soda (44 gm. of sodium hydroxid per 100 cc. of the cooled solution) and nearly complete the neutralization with a little powdered sodium carbonate.[25] Transfer to a 250 cc. flask with water, cool to room temperature, make up to the mark, and mix well. Filter, if necessary, and determine the dextrose in a 50 cc. aliquot of the filtrate, by copper reduction, employing the gravimetric method either of Munson and Walker or of Allihn. Correct the weight of dextrose obtained by the weight of dextrose [26] found for the same aliquot of the malt control, and multiply the corrected weight of dextrose by 0.90 to obtain the weight of starch. (This factor 0.90 represents the theoretical ratio between starch and dextrose and was used throughout this study, although several other investigators (*1, p. 95*) have shown that the factor 0.93 more nearly represents the actual yield.)

ALIQUOTS

$$\text{Charge} \times \frac{200}{500} \times \frac{200}{250} \times \frac{50}{250},$$

or,

$$\text{Charge} \times 0.064.$$

SUMMARY

A method for the accurate determination of the starch content of material containing interfering polysaccharids is needed as an aid in the examination of impure linseed meals, apple products, and other substances containing important quantities of mucilage, pectin, or carbohydrates of that character.

Linseed meal is sometimes adulterated with weed seeds and other impurities. Unless these impurities are present in excessive quantities it is impossible to demonstrate such sophistication by the usual chemical analysis. The pure seed of the flax plant, however, contains no starch. As the nonflax material normally associated with flaxseed would contain no more than 50 per cent of starch, and the allowable limit of such nonflax material is 6 per cent,[27] any linseed meal containing more than 3 per cent of starch may be held to be adulterated.

The interfering polysaccharids are a serious obstacle to a correct determination of starch. Plant mucilages when moistened are practically impervious to water or weak alcohol. This prevents the leaching out of sugars by these solvents. Unless the mucilages and pectins, which are polysaccharids, are eliminated before the acid hydrolysis,

[25] Anhydrous carbonate is preferable, as it dissolves rapidly.

[26] In the official A. O. A. C. diastase method (*1*) the direction to "correct the weight of reduced copper" by that found in the malt blank is wrong.

[27] None of this 6 per cent shall be deliberately added.

they yield reducing sugars, thereby increasing the apparent starch content.

Several methods of analysis were formulated and tried, with varying degrees of success. The method finally adopted is based on: (a) Extraction of the material with ether, alcohol of from 25 to 35 per cent strength, depending on the material, alcohol of full strength, and finally again with ether to eliminate interfering soluble substances; (b) gelatinization and conversion of the starch by digestion with an infusion of barley malt; (c) elimination of interfering polysaccharids by precipitating these substances in 60 per cent alcohol; (d) evaporation of the filtrate to drive off the alcohol, and subsequent acid hydrolysis of the starch conversion products; (e) defecation of the resulting dextrose solution with phosphotungstic acid; and (f) determination of the dextrose by copper reduction.

A sample of starch for use as a standard was prepared, and definite quantities were added to charges of linseed meal of known purity. These charges were analyzed by the proposed method. From 97.2 to 99.9 per cent of the starch known to be present was accounted for by the determinations.

The possibility of adsorption of the starch conversion products by colloids coagulated by the 60 per cent alcohol was investigated, by precipitating twice with 60 per cent alcohol and analyzing both filtrates. If there is any adsorption, for practical purposes the amount is negligible.

LITERATURE CITED

(1) ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS.
1920. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS. As compiled by the committee on revision of methods. Revised to November 1, 1919. 417 p., 18 fig. Washington, D. C. Bibliographies at ends of chapters.

(2) CASSAL, N. C.
1911. NOTE ON THE COLORIMETRIC ESTIMATION OF STARCH. *In* Chem. Engin. and Works Chemist, v. 1, p. 68–70.

(3) DAVIS, William A., and DAISH, Arthur John.
1914. METHODS OF ESTIMATING CARBOHYDRATES. II. THE ESTIMATION OF STARCH IN PLANT MATERIAL. *In* Jour. Agr. Sci., v. 6, p. 152–168, 1 fig.

(4) HORTON, Edward.
1921. ON THE USE OF TAKA-DIASTASE IN ESTIMATING STARCH. *In* Jour. Agr. Sci., v. 11, p. 240–257.

(5) NEVILLE, Allen.
1913. LINSEED MUCILAGE. *In* Jour. Agr. Sci., v. 5, p. 113–128.

(6) SCHNEIDER, Edward C.
1912. A NUTRITION INVESTIGATION ON THE INSOLUBLE CARBOHYDRATES OR MARC OF THE APPLE. *In* Amer. Jour. Physiol., v. 30, p. 258–270. Bibliographical footnotes.

(7) VAN KAMPEN, G. B.
1914. DER GEHALT DES LEINSAMENS AN WASSERLÖSLICHEN KOHLENHYDRATEN. *In* Landw. Vers. Stat., Bd. 83, p. 471–476. Bibliographical footnotes.

(8) WALTON, G. P.
1918. REPORT OF CHAIRMAN, LINSEED PRODUCTS COMMITTEE, ASSOC. FEED CONTROL OFFICIALS, U. S. *In* Flour and Feed, v. 18, no. 9, p. 38–39.

BIOLOGICAL NOTES ON THE HEN FLEA, ECHIDNOPHAGA GALLINACEA[1]

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With the considerable increase in poultry production in the Southwest the hen flea (*Echidnophaga gallinacea* Westwood) is becoming more and more of economic importance. For this reason a biological study of the flea has been made at Uvalde, Tex., as time has permitted and as opportunity to obtain material has been presented. The work has consisted of observations on life history, seasonal abundance, and natural control, and some investigations on artificial control.

METHODS USED IN OBTAINING THE LIFE HISTORY

It was found very difficult to breed the fleas under laboratory conditions that would permit observation of individual development. The immature stages require an almost ideal condition for development. The degree of moisture in the breeding media must have a very narrow range of fluctuation, and the range of temperature within which the fleas will develop is probably rather narrow, although this point has not been very definitely determined. Apparently the optimum temperature ranges from 70° to 80° F.

For individuals or only a few specimens 5-gm. shell vials were used. Two cm. of fine dust screened from the floor of a chicken coop in which chickens heavily infested with the adult fleas were kept were placed in the tubes, care being used to obtain as much of the flea excreta as possible. This was collected by placing a heavy paper in the coop at night and removing it about sunrise the next morning The débris was then screened, and the screenings were examined for eggs. The tubes were closed by using a piece of sponge dipped in water, squeezed nearly dry, and stuffed loosely into the mouth of the tube. Pint Mason jars and tumblers holding about a half pint were used and filled about half full of the screenings. A moistened sponge was pinned to a muslin cover and suspended in the jar. It was unnecessary to use the sponge in larger containers unless the humidity was very low, but it was necessary to cover the container with a muslin cover rather than a close-fitting cover such as the glass top to the museum jars used. These jars were about 5 inches in diameter and held about 3 quarts.

INCUBATION

The incubation period has been found to vary from a minimum of 4 days to a maximum of 14 days, although the usual period is from 6 to 8 days. The minimum period was obtained when the temperature was

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quite uniform, with a maximum of 86° F., a minimum of 69° and an average of 76°. The maximum period was obtained in a mass in a tumbler in which the incubation varied from 9 to 14 days. Records of the temperature of the room in which the jars were kept were not obtained, but the temperature was held rather uniformly at about 65° during the day. The lowest temperature observed in the room was 43°. The average temperature in the insectary was 47°, the maximum 80°, and the minimum 17°. The low temperature was registered on the second day, and several of the eggs failed to incubate; these were probably the ones on the outer edge of the mass. About 43° may be considered a fatal temperature for the eggs.

LARVAL DEVELOPMENT

The larvæ usually begin to feed on the adult excreta within a few minutes after emergence and develop rapidly for the first few hours. The excreta of the adult are apparently necessary for the development of the young, and these latter have never been observed to feed on any other material. The fatal minimum temperature is about 50° F., and all the larvæ in an incubator died within a few hours when the temperature was 100° near the tube in which they were placed. The minimum larval period was 14 days; the maximum, 31 days.

PUPAL PERIOD

The mature larvæ construct cocoons of silk and dust. Apparently they prefer to fasten them to some firm object, as a large percentage made the cocoons against the side and bottom of the breeding container and in many cases the pupæ could be observed through the glass. The pupal period was found to be from 9 to 19 days.

ADULT DEVELOPMENT AND HABITS

The adults were inactive during the first few days after emergence and usually did not attach to a host until the fifth or eighth day. The females became engorged and oviposition began in from 6 to 10 days after attachment. Females deposited from one to four eggs per day, and oviposition took place during both day and night.

The following notes were made on the act of oviposition: A well engorged flea was observed in the act of passing excreta and in 18 minutes it was observed to be passing an egg. In 45 seconds the egg was thrown with considerable force and was apparently free for several seconds before it was thrown. While examining a flea on the head of a chicken a bright drop of fluid appeared; in 10 seconds an egg appeared, and in less than 5 seconds it was thrown with considerable force. The adult was observed to pass more fluid, and in 45 seconds another egg appeared and was thrown in less than 30 seconds. Nothing else was observed to pass during the next half hour. Practically all oviposition observed has taken place while the fleas have been attached to the host. The adults remained attached on the host from 4 to 19 days in the same place. It was not determined whether they reattach after once dropping.

Copulation has been observed to take place on the host. The fleas were attached on the head of the chicken about the length of the body apart and were ventrally by slightly laterally together. They were in

copula when observed and remained so for 35 minutes, until they were slightly disturbed and the act ended.

The adults are killed by freezing temperature and die within a few hours when exposed in tubes in an incubator at a temperature of 100° F.

TOTAL PERIOD OF DEVELOPMENT, LONGEVITY OF ADULT FLEAS, AND CONDITIONS AFFECTING ABUNDANCE

The minimum period from oviposition to the emergence of the adult was 30 days and the maximum period 65 days.

Eggs, larvæ, and pupæ were kept in a jar with the original breeding media from December 8 until April 18, when some adults were still alive after a period of 132 days. The adults can live for a considerable time without food under some conditions, and an infestation will persist for at least two months in the adult stage if the weather is dry and cool. Adults die very quickly without food if the weather is hot.

Breeding occurred during the winter of 1921–22, at Uvalde, Tex., in unprotected places where a large number of chickens were kept—that is, in open yards and under trees in which the fowls roosted. These infestations increased during the winter and early spring until they were very heavy in the latter part of March. The fleas practically disappeared immediately after the heavy rains of March 29 and April 3 and 4. Two weeks after the rains it was unusual to find a flea on the fowls in such places if the latter were not permitted to go under buildings. It has been observed that the fleas become abundant during the fall or spring of the year when the weather is cloudy and dry, a condition that occurs frequently in southwestern Texas. Infestations are likely to occur at any time in cool, dry places, as under buildings and in closely constructed henhouses.

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